UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Automated Water Quality Monitoring

Electrical & Computer Engineering

Team 67

May 6th

Introduction

Team

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CompE & Business Minor (3D Printing, Mechanical, and Design Lead)

- **Investment Analyst at RAED VC**
- **Business Analyst & Data Scientist at Mozn**

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Electrical Engineer (PCB and Code Lead)

- **Signal Integrity Assistant Researcher at UC Irvine**

Objective: Problem We’re Solving

Problem

Current Market Solutions & Their Limitations

High-end Electronic Meters

- Extremely costly (hundreds of dollars)
- Accuracy still falls short of chemical tests

Budget Hardness Kits

- Very cheap, but tests limited parameters

Colorimetric Test Strips

- Multi-parameter coverage
- 100% reliant on human color matching → inconsistent readings

Automatic Water Quality Monitoring Using Test Strips

We are building a fully enclosed device that **automates** every step of chemical test-strip analysis to deliver lab-style consistency in everyday settings at an affordable cost

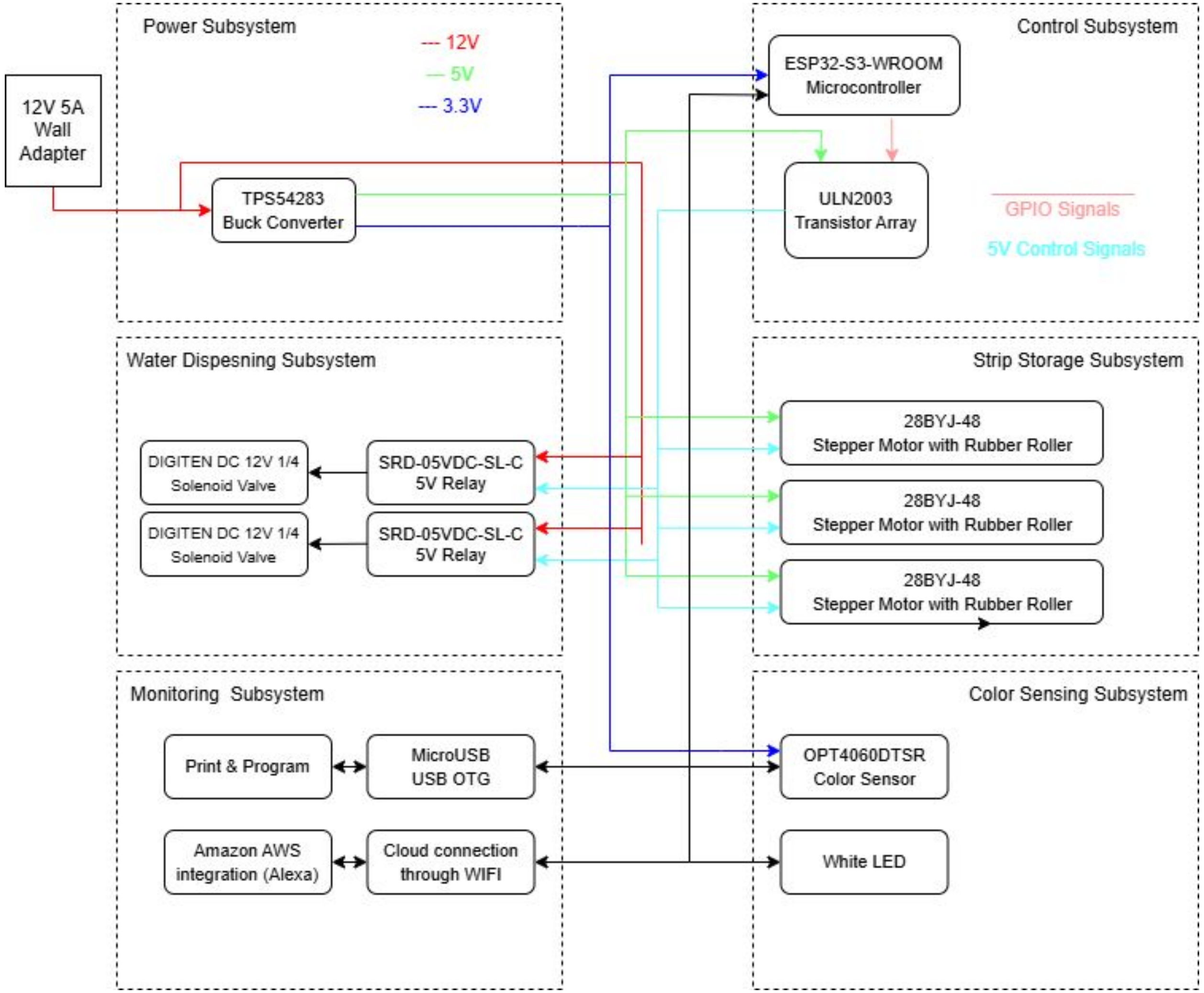
Key Features

- Fully enclosed test-strip handling (dispense ▸ soak ▸ read ▸ discard)
- Gravity-fed water delivery with precise solenoid control
- RGB color sensor + controlled LED lighting for objective color measurement
- ESP32-based control + logging for real-time and historical data
- Cloud connection through AWS to allow smart home integration.

Design Overview & Requirements

Design Overview

Block Diagram

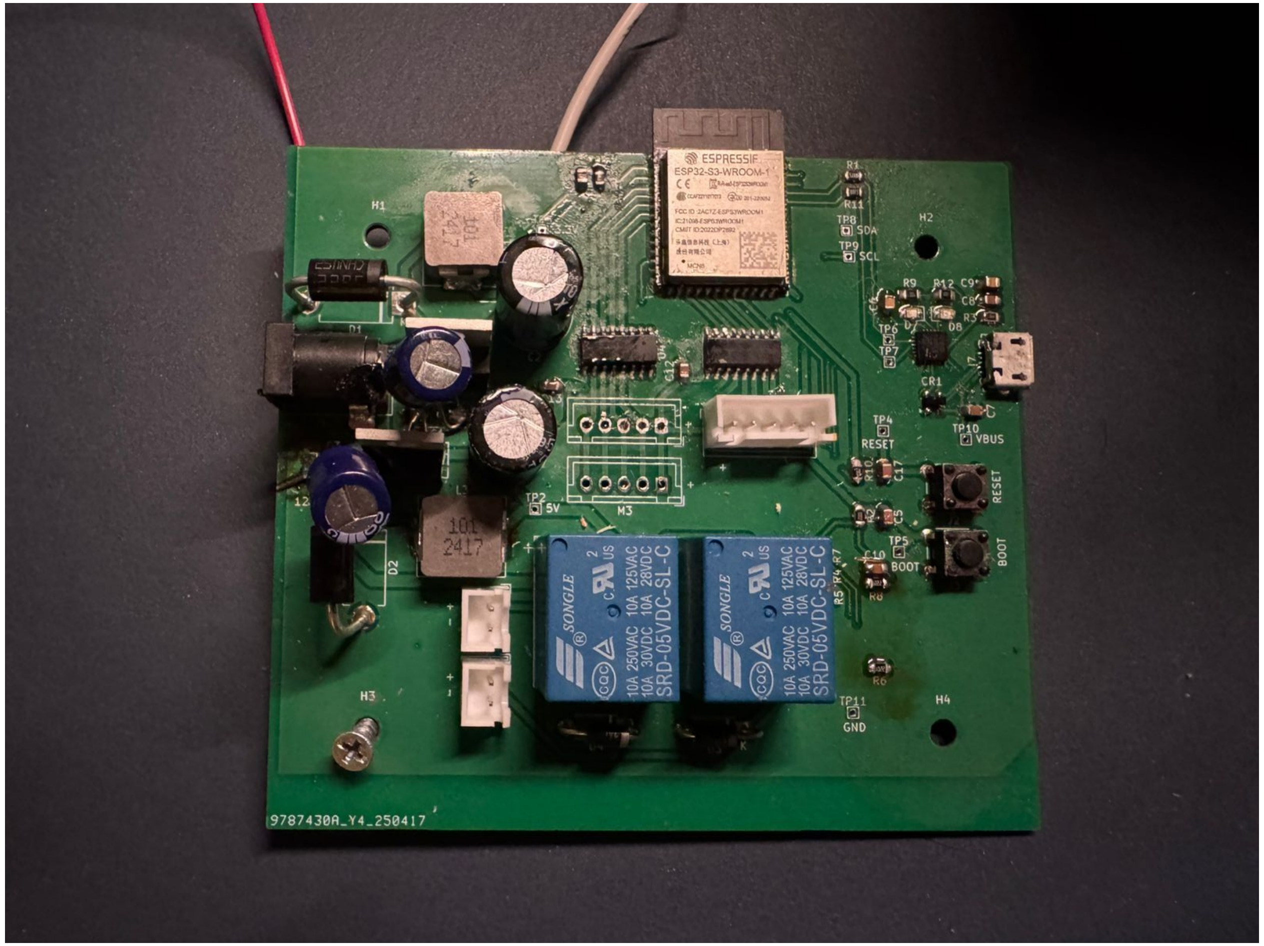


High Level Requirements

Proper strip feed and discard onto the belt

Correct placement and water dispensing behavior

Cycle time < 60 s



Fully soldered PCB

Power SubSystem

Overview

The power subsystem supplies consistent and reliable power to all other subsystems.

12V/5A Wall Power Brick

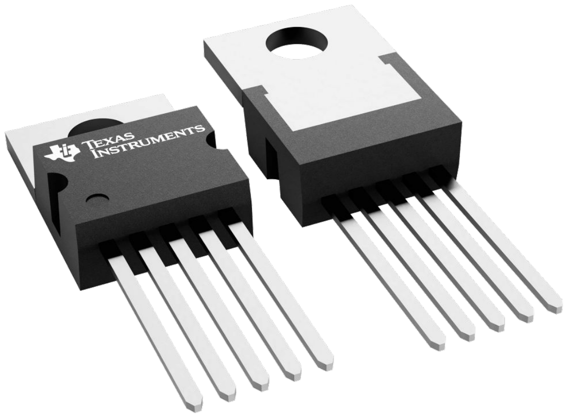
- Built-in over-current & short-circuit protection
- Provides a stable 12V supply

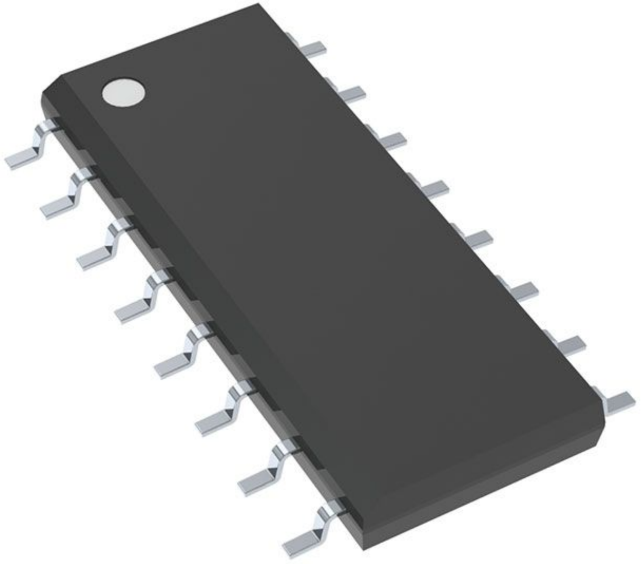
LM2576T/3.3 & LM2576T/5.0 Buck converters

- Steps down 12V to 3.3 and 5V

ULN2003 Transistor Array

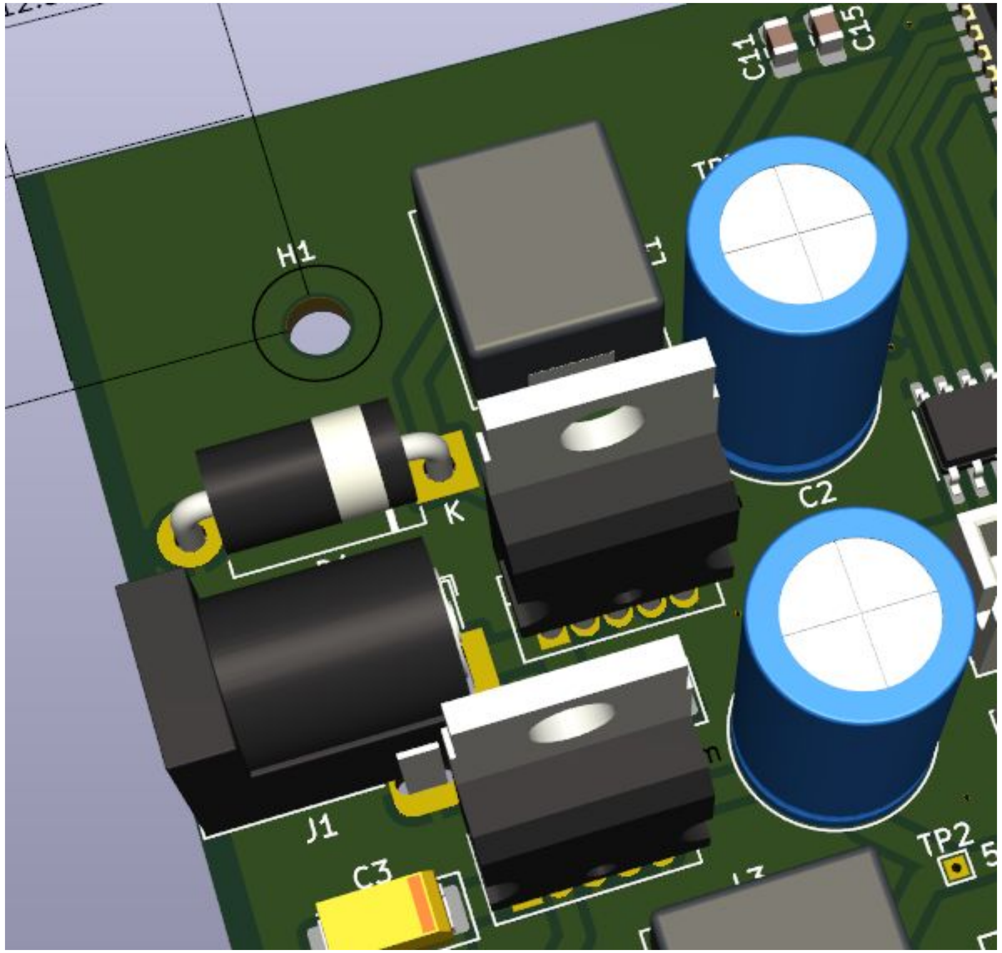
- Boosts the ESP32 GPIO Signals to control relay and stepper motor



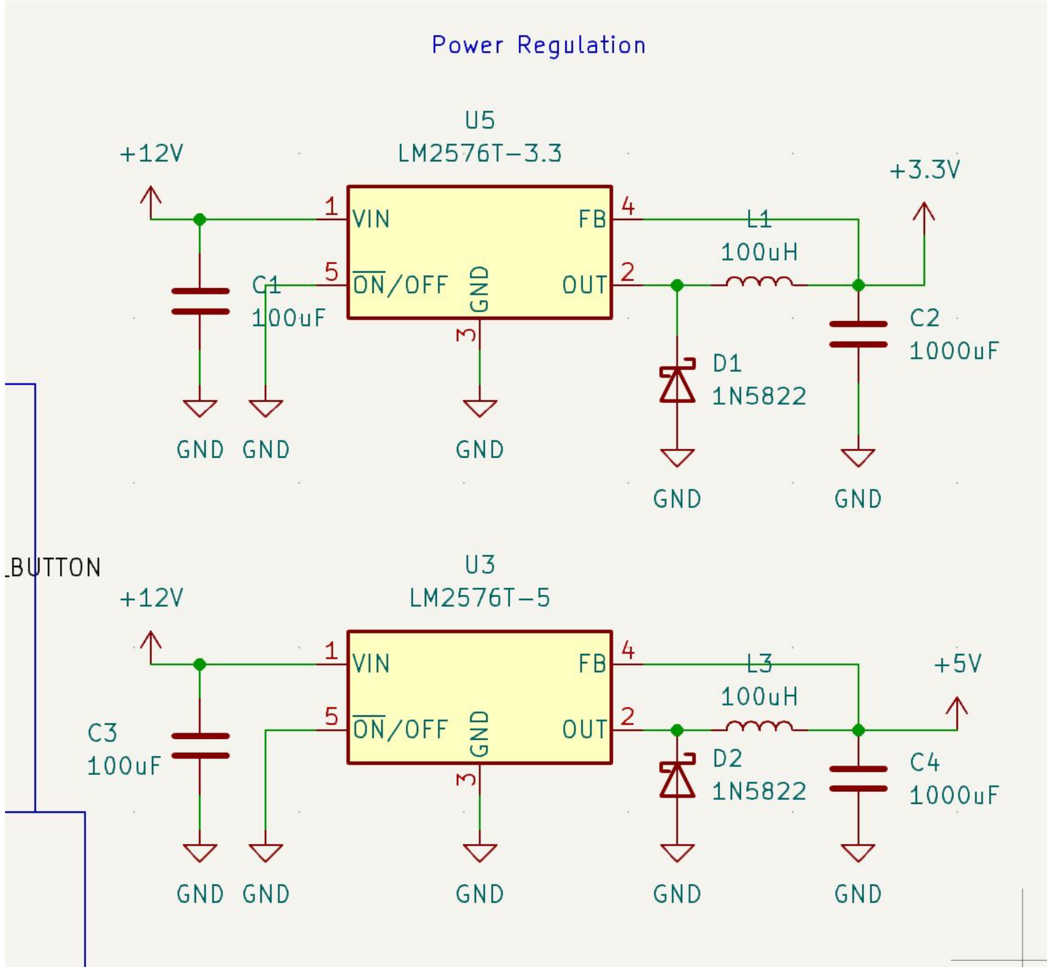


Power SubSystem

Subsystem 3D Model



Circuit Schematic



Control + Monitoring Subsystem

Overview

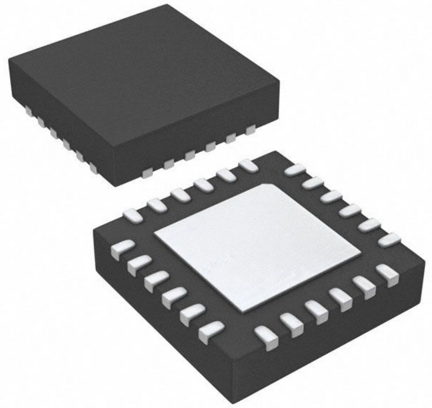
The ESP32-based control unit acts as the system's "brain," sequencing every stage of the test cycle and managing all data communication.

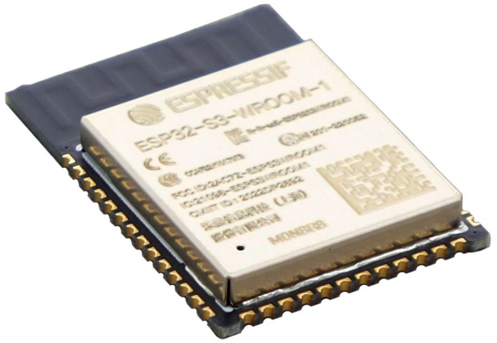
ESP32-S3-WROOM Module

- Dual-core 240 MHz MCU with Wi-Fi & native USB OTG
- Runs an interrupt-driven finite-state machine

GPIO Control Lines

- Drive ULN2003 array for stepper motor and 5 V relay actuation.





I²C Interface

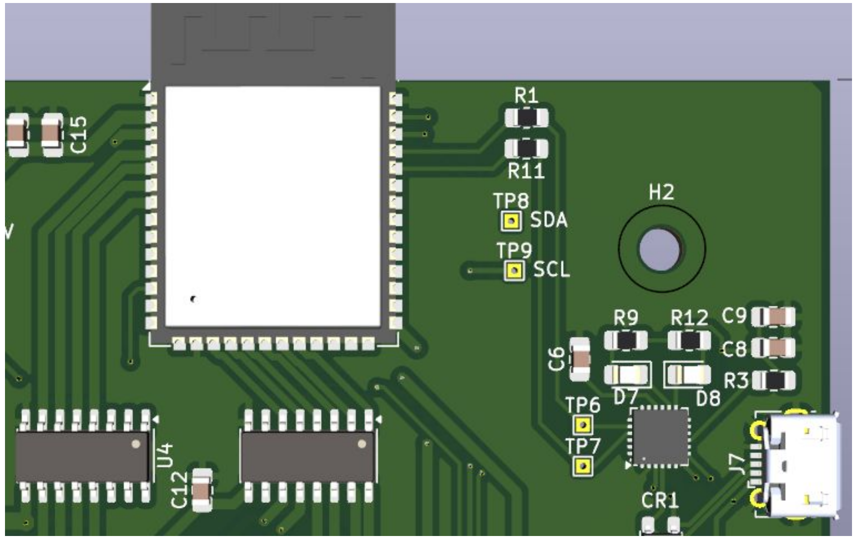
- Polls OPT4060 color sensor for tristimulus data

Data Logging & Cloud

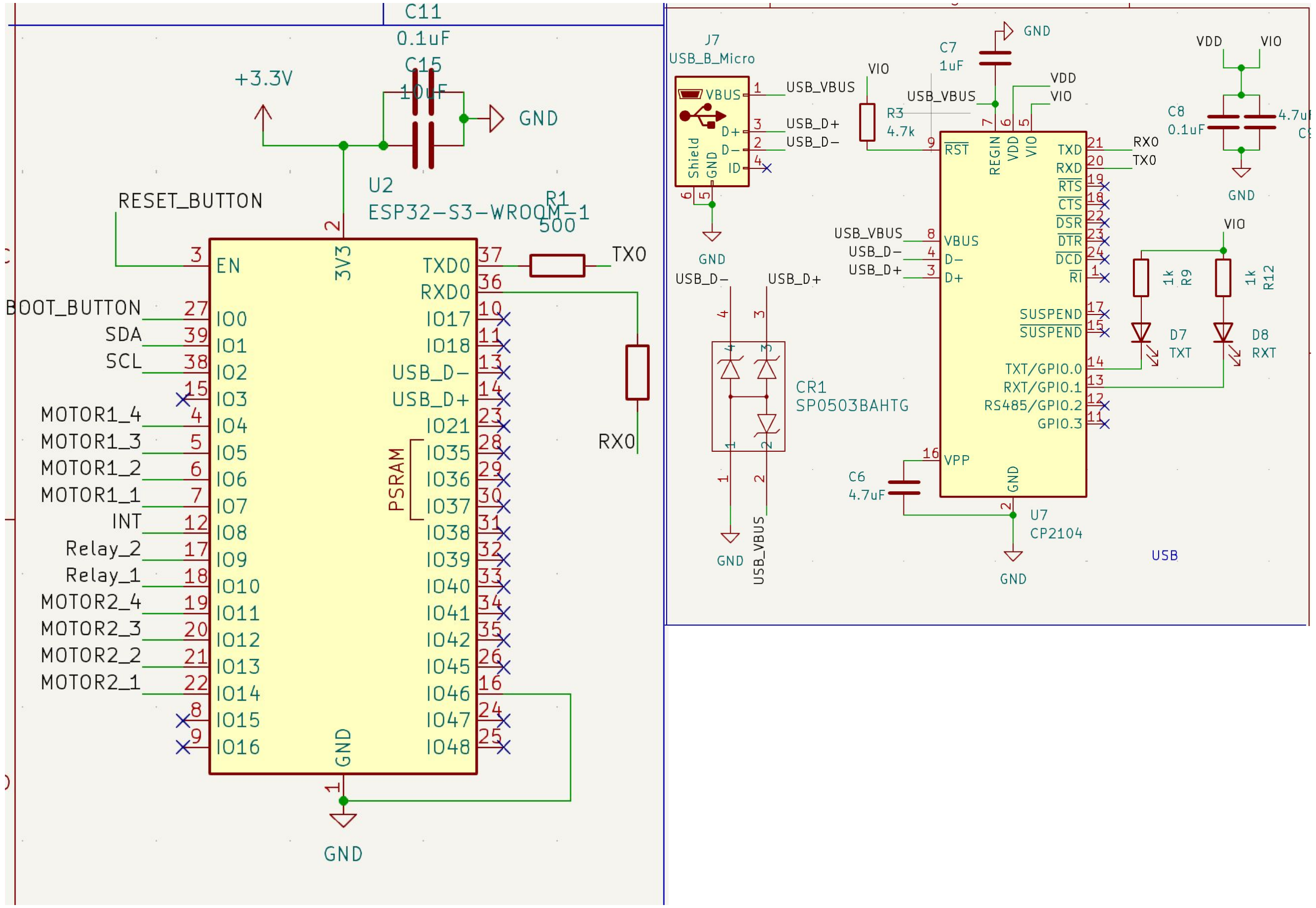
- Structured USB serial stream to logger
- ESP RainMaker AWS Wi-Fi upload.

Control + Monitoring Subsystem

Subsystem 3D Model



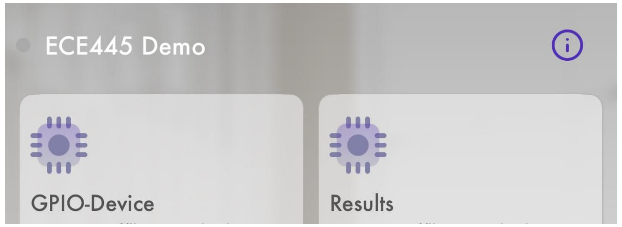
Circuit Schematic

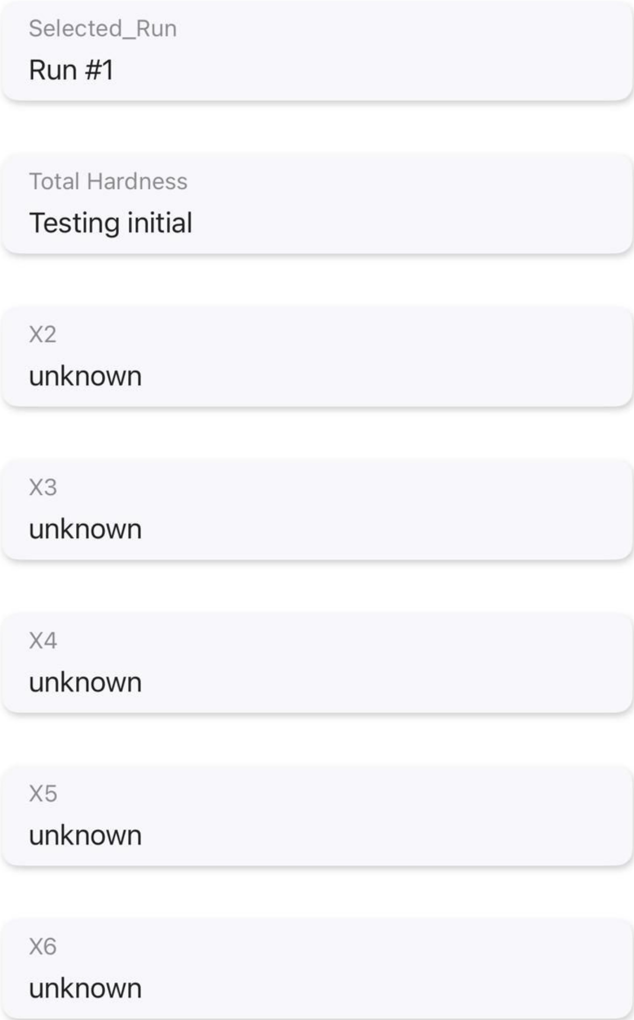


Control + Monitoring Subsystem

Alexa-Enabled Control Button

- Simple “Start Test” toggle
- Exposes a single Boolean endpoint to Alexa
- Enables voice-activated triggering
- Decouples voice interface from data flow





ESP-RainMaker Data Host

- Publishes readings to RainMaker cloud
- Dashboard & mobile app visualize trends in real time
- Sends alerts if parameters exceed thresholds

Water Dispensing SubSystem

Overview

Delivers a precise, repeatable water dose to activate each test strip.

Gravity-Fed Reservoir

- Elevated 500 mL tank provides consistent head pressure without a pump.

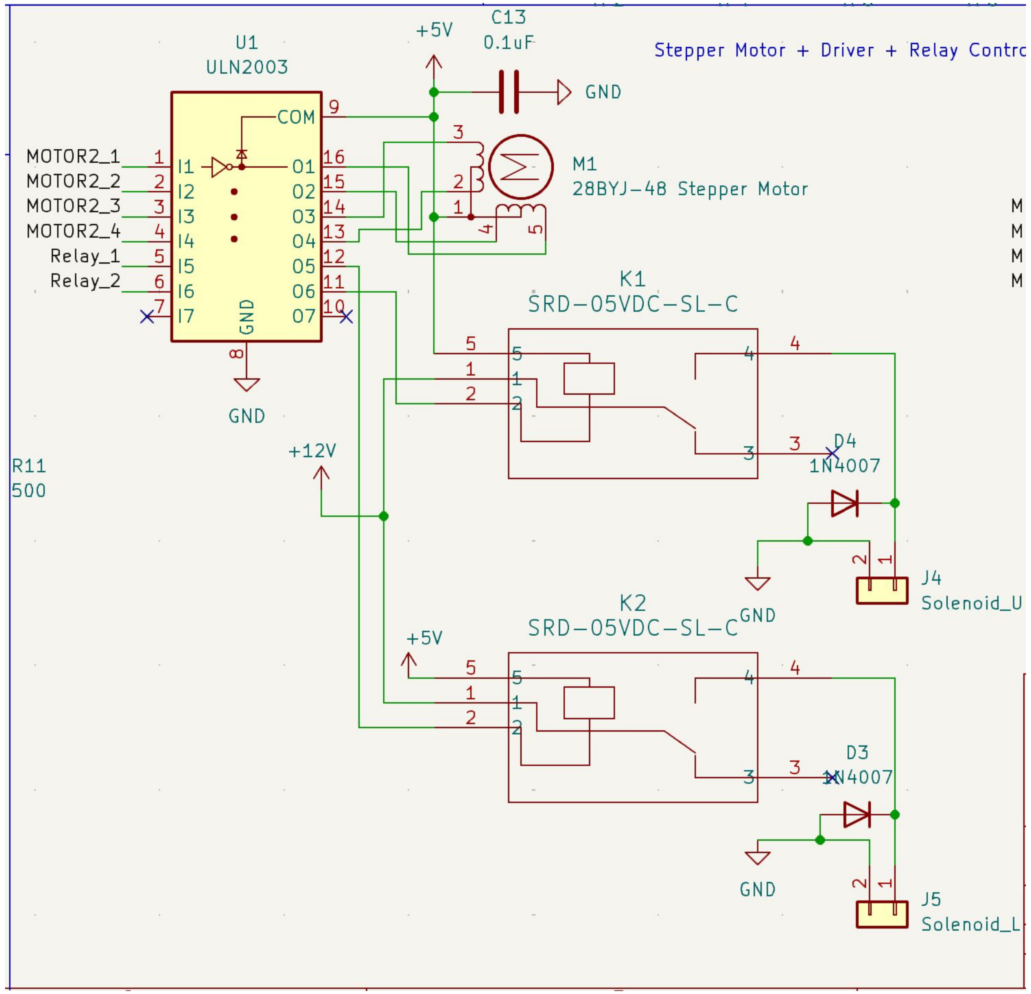
Timed 12 V Solenoid Valve

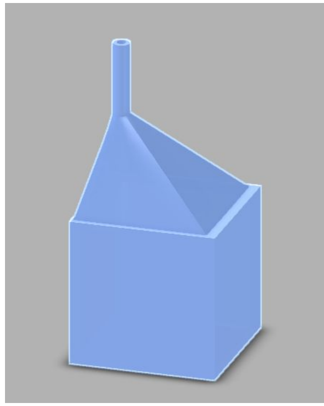
- Driven by 5 V relay through ULN2003 interface.

Calibration Mode

- Valve-open via UART command for easy flow tuning.

Components & Circuit Schematic





Overview

Feeds one test strip at a time from the magazine and positions each pad precisely under the dispenser and sensor.

Vertical Magazine

- Holds 20+ test strips; guide protrusions ensure only the bottom strip contacts the drive belt.

Timing-Belt Feeder

- Closed-loop belt driven by 28BYJ-48 stepper;

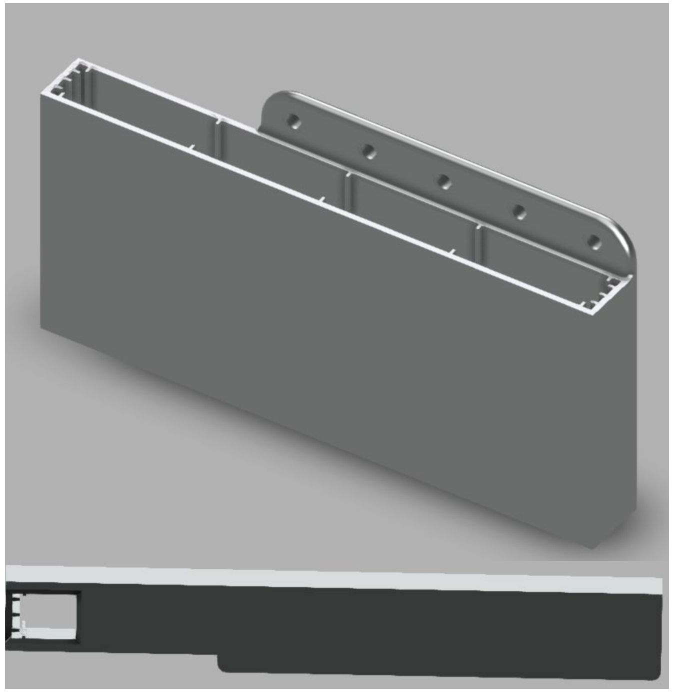
Low-Friction Guide Rails

- Keep strip flat and centered—no rollers required, reducing wear and jams.

ULN2003 Driver Interface

- Translates ESP32 3.3 V GPIO to 5 V coil signals

Components



Overview

Transforms the test strip's pad colors into precise digital values for chemical concentration analysis.

OPT4060 Tristimulus Sensor

- I²C device captures XYZ/RGB values with 16-bit resolution.

White-LED Ring Illumination

- White LEDs provide uniform, repeatable lighting for every pad read.

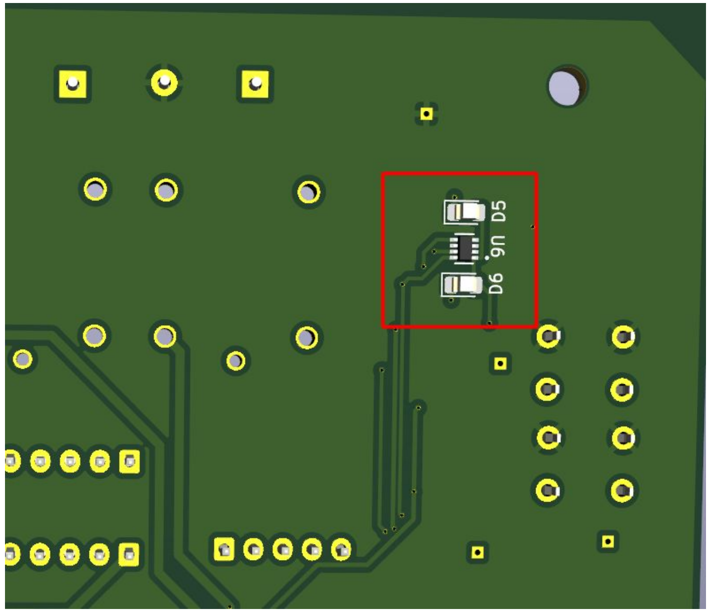
Fast Readout Pipeline

- ESP32 polls sensor at 400 kHz; raw data processed and sent in ≤ 5 s.

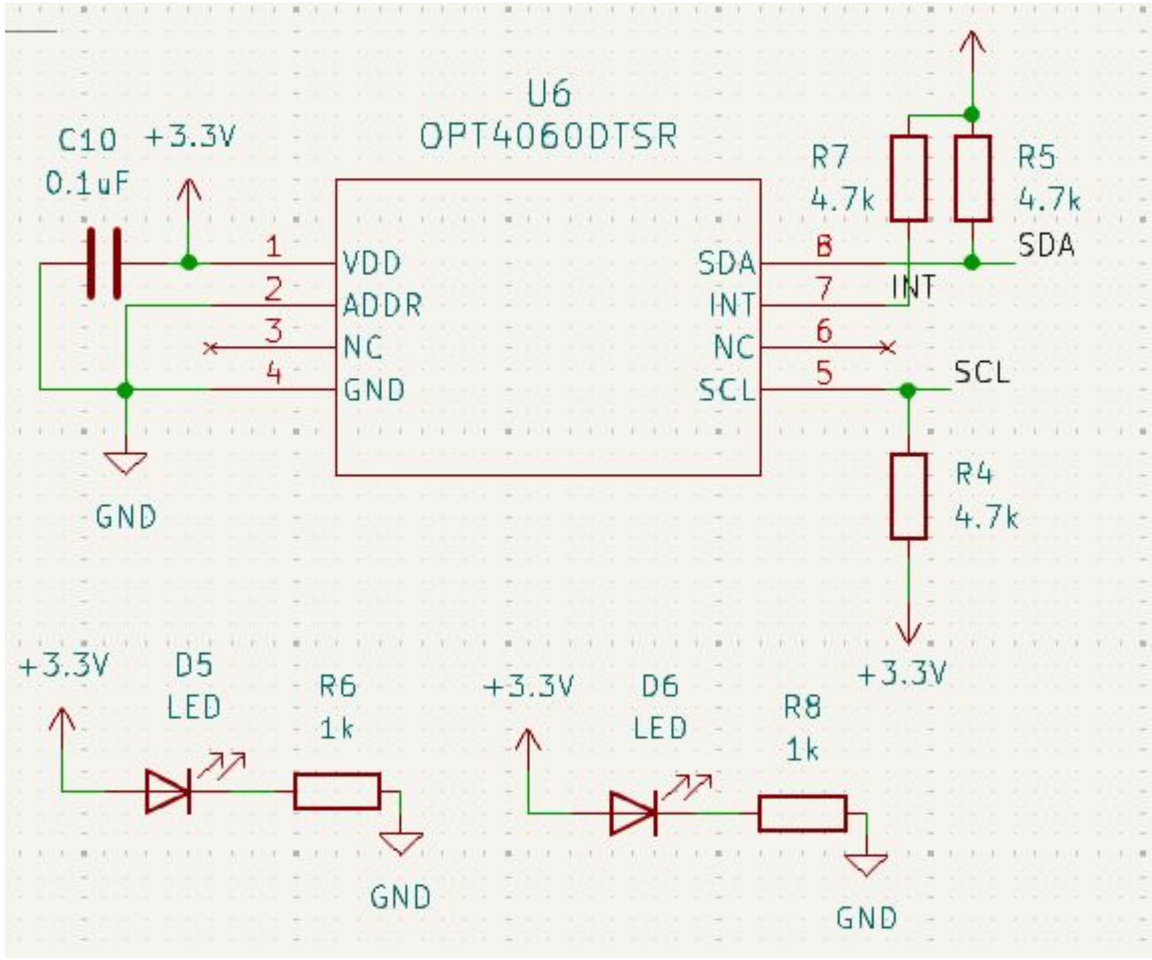
Circuit Schematic

Color Sensing SubSystem

Subsystem 3D Model

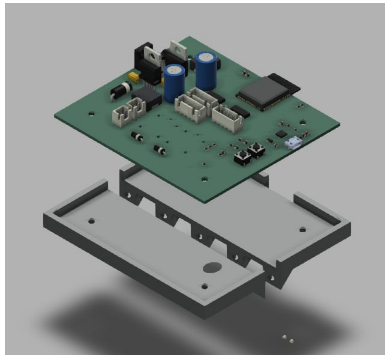


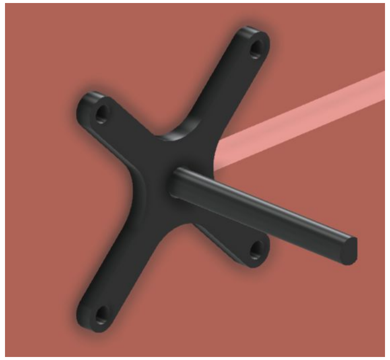
Circuit Schematic

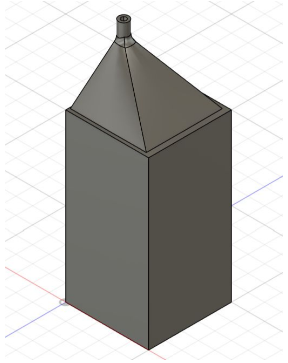


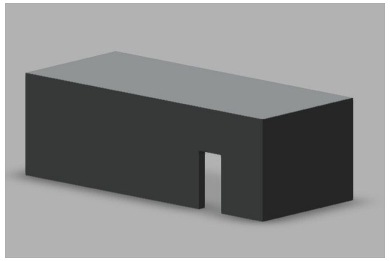
3D Printed Parts

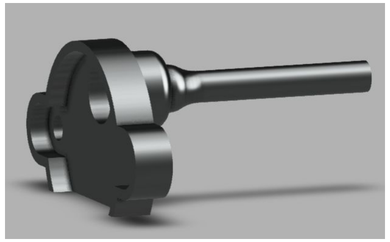
Individual 3d Parts


PCB Holder

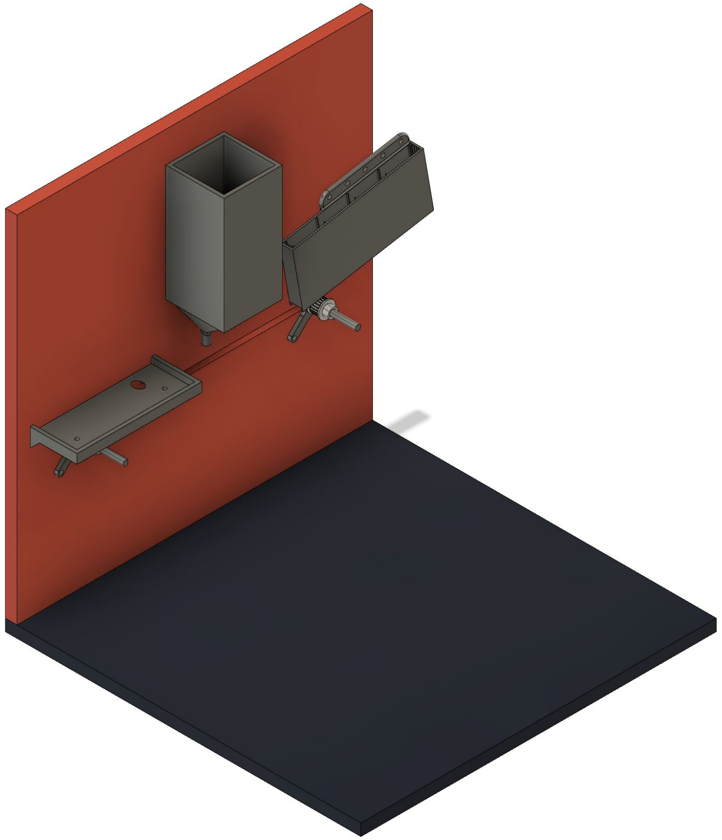

Shaft Holder


Water Tank


PCB Cover


Motor Holder

Overall Design Assembled



Design Changes

Key Design Changes

Simplified Valve System

- Switched from two valves + intermediate pipe to a single valve
- Eliminates risk of vacuum “lock” in the pipe
- Reduces plumbing complexity and cost
- Improves reliability and ease of control

Timing-Belt Drive

- Replaced rubber rollers with a **timing belt** mechanism
- Ensures precise, repeatable strip positioning (no slip)
- More durable, ideal for our demo’s on-off operation
- Cleaner integration into our sealed fluid system

Test Results

Key Milestones

Electronics

- Two-layer PCB fully soldered: ESP32, dual-buck power, ULN2003 driver, relay.
- Fully programmable PCB for every subsystem
- Customizable variables for strip dimensions allowing for different kinds of test strips

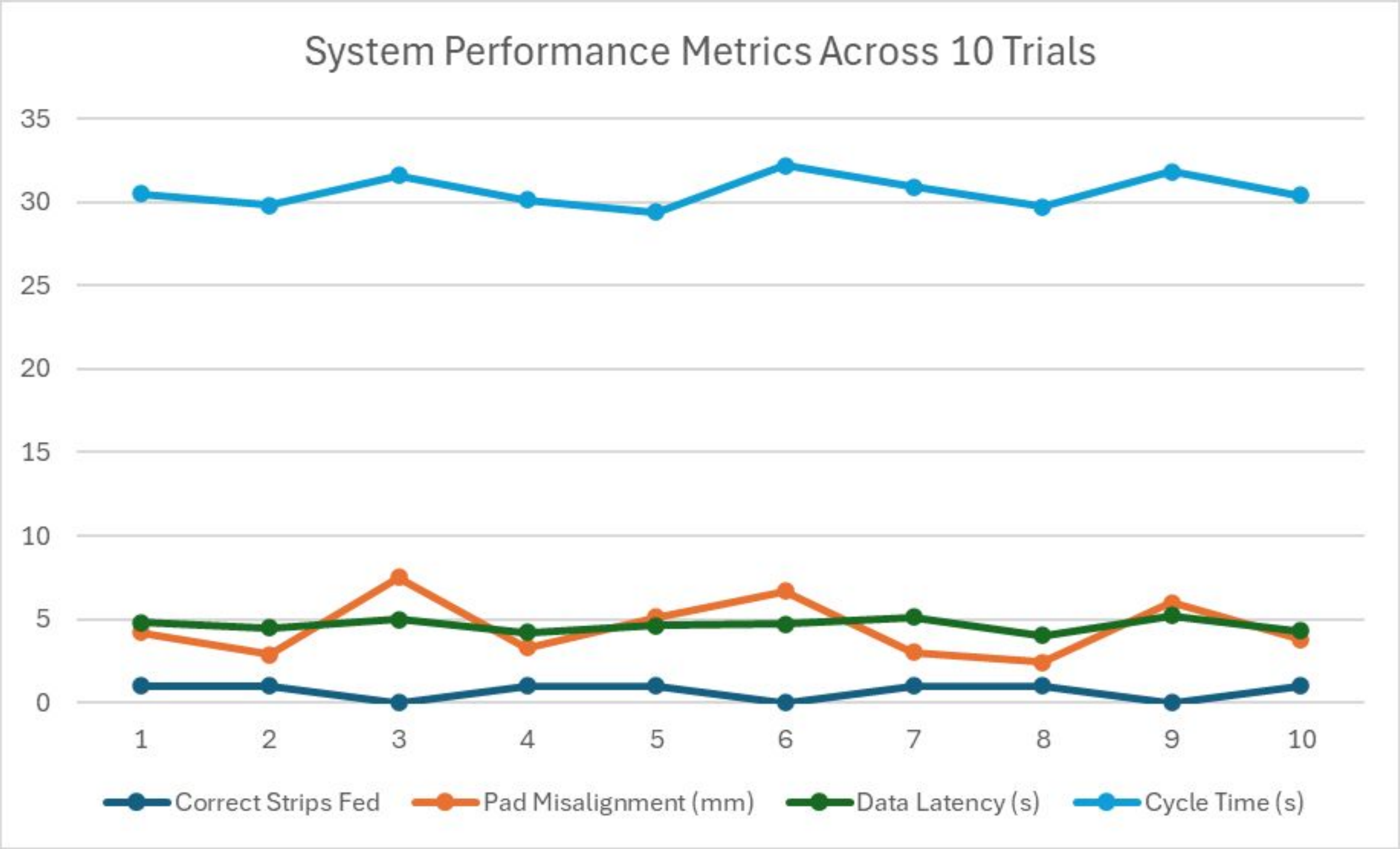
Mechanics

- Timing-belt feeder & vertical magazine 3-D-printed in PETG
- Individual mechanical subsystems validated
- All subsystems mounted on modular plates for easy service. and replacement.

Integration

- ESP32 firmware flash & USB logging verified; AWS RainMaker provisioning successful.

Functional Test Results



Functional Test Results

Test	Target	Result
Strip feed reliability	≥ 90 % single-feed	90% (9/10)
Pad alignment	**±0.5 cm**	**±0.3 cm** average error
Data latency (Scan Data)	≤ 2 s	4.64 s
Full cycle time	< 60 s	30.64 s

Challenges

Main Challenges

Color Sensor Constraints

- Requires **~3 mm** standoff for accurate OPT4060DTSR reading. This is especially difficult considering **mechanical constraints.**
- Must be **isolated** from ambient light and is very **sensitive** to environment changes.

Solenoid Valve Challenges

- Valve switching speed **too slow** for single water drops.
- Flow variability makes it hard to deliver **consistent 1 mL doses**.
- **No apparent issue** with results, as strips are designed to handle **more** volume.

Mechanical Design

- Timing-belt feeder needed **multiple redesigns** to prevent skew and jams.
- **Tight space** complicated alignment of belt, sensor, and valve.

Conclusion

Key Learnings

PCB Design

- **Translating** a block diagram into a **compact**, manufacturable two-layer board.
- Use traces of proper width for current needs to **reduce** noise and heat.
- Using **DRC**, net-labeling, and test points early to **minimize** post-fabrication **rework**.

3D Printing & Fusion 360

- Rapid CAD-to-print iteration **lowers risk** fit issues are tested and caught early.
- Understanding **material properties** (PETG, PLA) and **tolerances** for friction fits and snap joints.
- Designing **modular parts** that align reliably without jigs, simplifying final assembly.

Wi-Fi Communication

- Publishing sensor data to a dashboard enables **remote monitoring** and firmware OTA updates.
- **AWS** for **alerts** and data **retention** without building a custom backend.

Future Work & Suggested Design Changes

Future Plan

01 Color Sensing

- Use a longer-focal-distance color sensor to loosen mounting tolerances.

- Software calibration can compensate for ambient-light drift and aging LEDs.

02 Water Metering

- Replace on/off solenoid with a pinch-valve pump for precise dosing.

- Closed-loop flow control would let us hit ±2 % volume instead of timing-based estimates.

03 Lighting Calibration

- Integrate a fixed white reference pads for periodic self-calibration.

- Keeps color-reading accuracy stable over time

04 Feedback Sensors

- Optical flag for strip presence and a small flow sensor for real-time volume confirmation.

- Feedback allows the controller to pause on jams and self-adjust water-delivery timing.

Ethical Considerations

Ethical & Safety Highlights

- **Public Safety First** — enclosure isolates electronics from water; automatic shut-down on fault (IEEE Code of Ethics §1).
- **Honest Results** — device labels readings as *screening estimates*, not certified lab data; limits disclosed to users.
- **Data Privacy** — cloud upload is optional and encrypted; no personally identifiable data stored (ACM Code 2.5).
- **Environmental Care** — spent strips collected for safe disposal; low-power (< 5 W) design reduces energy impact.

(All practices align with IEEE & ACM Codes: prioritize welfare, ensure integrity, protect privacy.)

Questions?

Contact Information

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