ECE 445 - Senior Design Lab

Project Proposal

Automatic Water Quality Monitoring using Test Strips

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Introduction

Problem

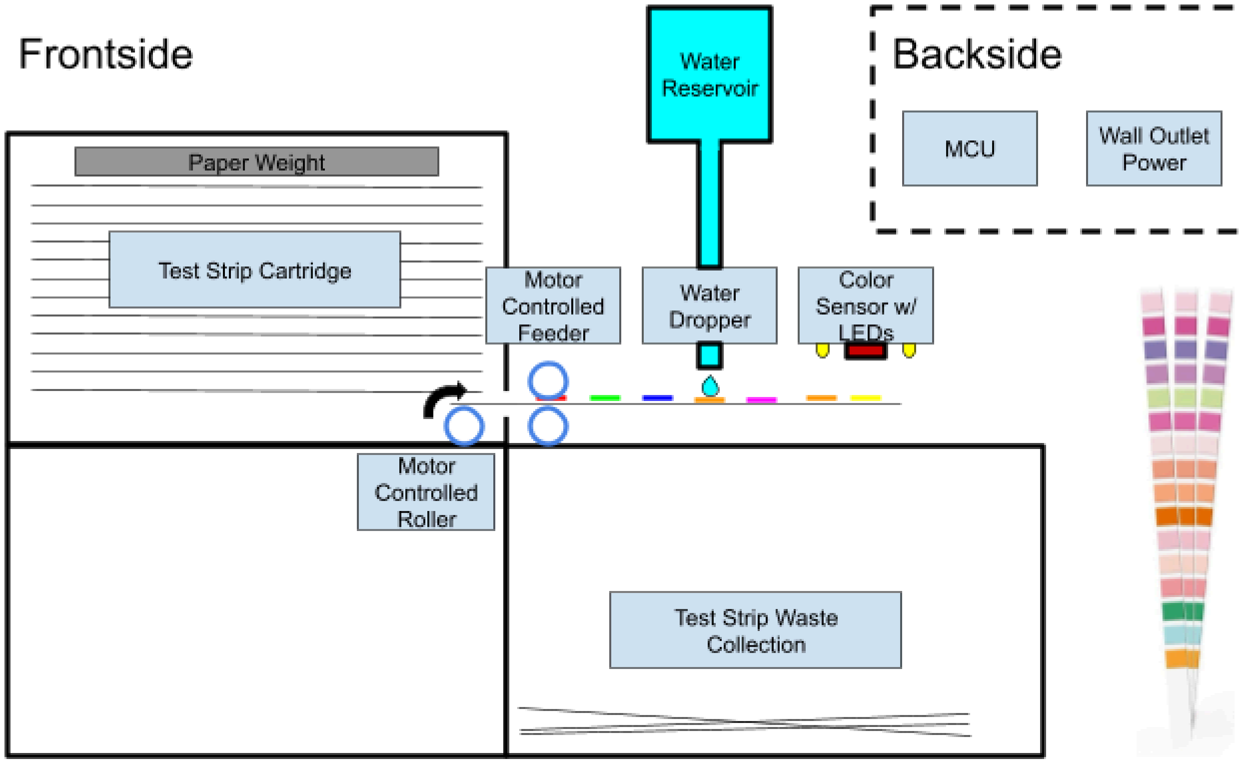
Water quality testing is recommended by the Environmental Protection Agency (EPA) for ensuring safe water consumption and alerts to poor water quality in homes and industrial settings [1]. Frequent water testing can provide human owners with early warnings of water crises such as lead contamination in Flint Michigan [2]. Traditionally, getting accurate measurements relies on lab-controlled testing with specialized equipment [3]. Due to their high cost, lab testing is mainly reserved for industrial applications and options for at-home testing include digital measurement devices and, most commonly, chemically reactive paper test strips. These test strips react chemically with water samples, requiring users to manually interpret color changes against reference charts. This method is time-consuming and susceptible to human error due to variations in lighting conditions and subjective color interpretation. While digital alternatives exist for some tests, such as pH meters, they tend to be expensive, require calibration, and do not support a wide range of compound and elemental tests. This gap highlights the need for an automated system capable of handling multiple test strip types, standardizing the testing process, and improving accuracy. However, test strips are significantly less expensive and can measure more substances than digital measurement devices. Designing a hardware system to streamline the testing process provides frequent automated testing with higher accuracy, providing and storing results for users, and creating safer home environments.

Solution

Our proposed solution is an automated water quality monitoring system that utilizes traditional testing strips to eliminate manual effort and remove the effects of human perceptual error. The system consists of a fully enclosed mechanism designed to dispense water onto test strips, wait for the chemical reactions to complete, and accurately read the color changes using optical color sensors or a digital camera. Our test strip of choice contains 16 different chemical pads shown in the visual aid below which contain measurements for Nitrate, Nitrite, Total Hardness, Free Chlorine, Total Chlorine, Bromine, MPS, Copper, Iron, Lead, Nickel, Sulfite, Cyanuric Acid, Carbonate, Total Alkalinity, and pH with concentrations measured in parts per million (ppm) measured on different scales and colors for each substance. Each test pad will be tested sequentially and given the recommended 30 seconds to react before the color is read. Doing this sequentially also mitigates the problem of the test strip color fading from waiting too long while reading the colors.

The system will feature an automated feeder mechanism that retrieves test strips from a storage cartridge, a precise water dispensing system, an integrated color analysis module, and a used test strip collection system for the user to dispose of. Results will be displayed on a monitor or transmitted to a host system. This approach ensures consistency, accuracy, and efficiency while maintaining affordability by using widely available test strips instead of expensive digital sensors. By using a color sensing system with LEDs to control lighting conditions we can further decrease environmental factors.

Visual Aid



High-level Requirements List

- The system must automatically dispense a fresh test strip, apply water to fully saturate the test strip, and read the color change without human intervention at least once per testing cycle.

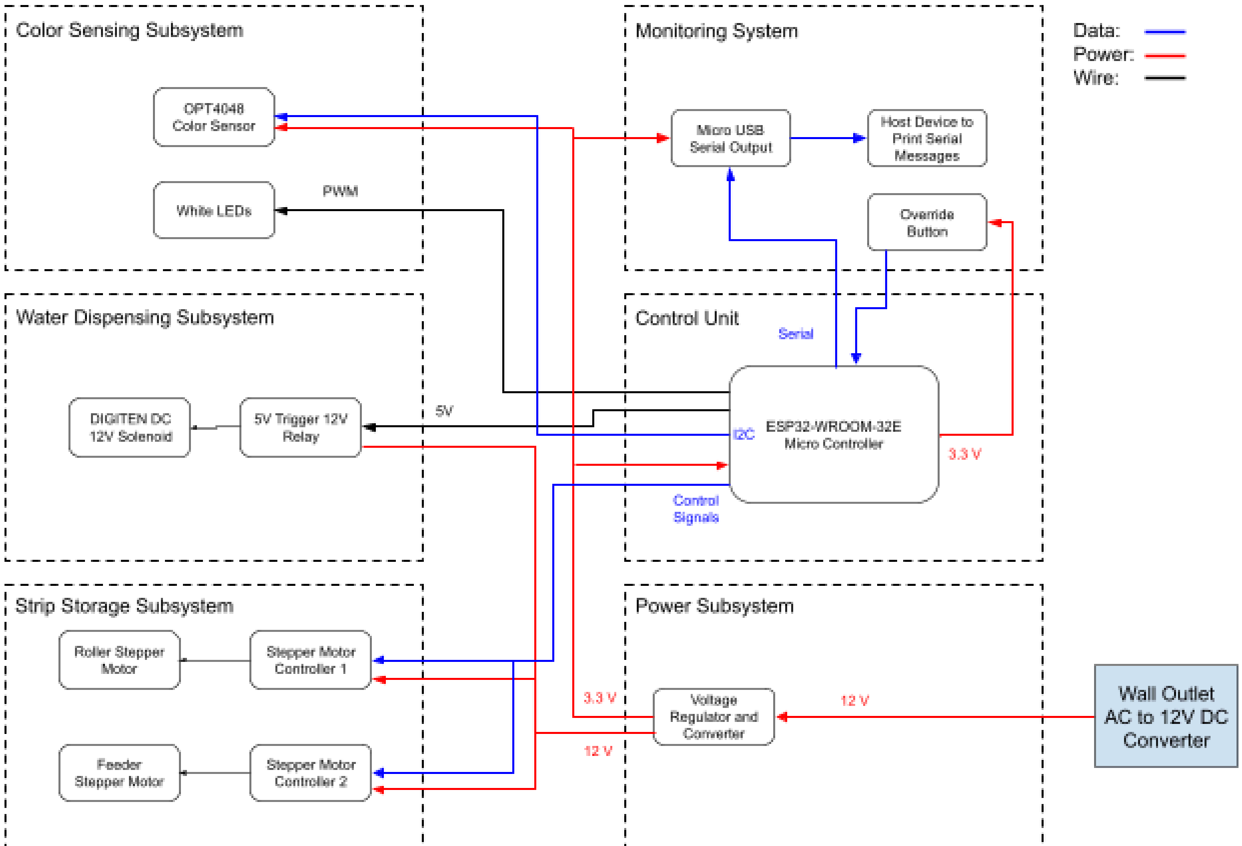
- The color detection module must be capable of analyzing the test strip with an accuracy of at least 80% compared to a human observer under controlled lighting conditions.

- The feeder system must accurately place the test strip under the water dispenser system and subsequently the color sensing system within (± 5mm).

- The system must be able to consistently output the same measurements using the same water sample when run over multiple test runs. The measurements must be within 10% accuracy of their average.

Design

Block Diagram



Subsystem Overview and Requirements

Subsystem 1: Color Sensing Subsystem

Overview:

This subsystem detects the color changes on the test strip to determine water quality. It comprises an RGB color sensor (OPT4048) [5] with controlled white LED lighting to ensure consistent and accurate readings. The data collected from this subsystem is processed and compared against predefined color values to determine chemical concentrations. It interfaces with the monitoring subsystem to display results and connects to the control unit via I2C for data transmission.

Requirements:

- Must be able to detect and interpret color changes with an accuracy of at least 80% compared to a human observer.
- Must interface with the monitoring subsystem via I2C to provide real-time analysis.
- White LED lighting must ensure consistent illumination of test strips to minimize errors.

Subsystem 2: Water Dispensing Subsystem

Overview:

The water dispensing subsystem is responsible for delivering a precise amount of water onto the test strip. It consists of a DIGITEN DC 12V Solenoid [6] controlled by a 5V trigger relay. The accuracy of the dispensing mechanism ensures that chemical reactions occur properly. This subsystem interacts with the strip storage and color sensing subsystems to ensure optimal test conditions. It receives control signals from the control unit to activate the solen

Requirements:

- Must deliver water with a precision of ±5% of the intended volume.
- Must prevent leakage or excessive water application that could interfere with test accuracy.
- Interfaces with strip storage and color sensing subsystems for correct test sequencing.

Subsystem 3: Strip Storage Subsystem

Overview:

The strip storage subsystem holds and dispenses test strips in a controlled manner. Using a motorized roller mechanism and a feeder stepper motor, it feeds a single test strip at a time into the testing chamber. It interfaces with the feeder system and water dispensing subsystems to ensure proper positioning and timing of the test sequence. Two stepper motor controllers (ULN2004A) [8] manage the roller and feeder stepper motors [7], receiving signals from the control unit.

Requirements:

- Must reliably dispense test strips one at a time without jamming.
- Must store at least a full pack of test strips to allow for multiple tests without frequent reloading.
- Interfaces with the feeder system and water dispensing subsystem to ensure test readiness.
- Must interface with the control unit via stepper motor controllers for controlled movement.

Subsystem 4: Monitoring Subsystem

Overview:

This subsystem processes and displays the test results. It consists of a microcontroller that reads data from the color-sensing subsystem and translates it into meaningful water quality metrics. The results can be displayed on an LCD or transmitted via a Micro USB Serial Output to an external host device for logging and further analysis. Additionally, an override button allows manual intervention if needed.

Requirements:

- Must process color data and provide water quality metrics within 10 seconds of testing.
- Must display results on an LCD or transmit data to an external system via Micro USB Serial Output.
- Must include an override button to allow manual operation if needed.

Subsystem 5: Power Subsystem

Overview:

The power subsystem supplies consistent and reliable power to all other subsystems. It includes a voltage regulator and converter to step down 12V power from the main AC to 12V DC converter to required voltage levels (3.3V and 5V). Proper power management ensures uninterrupted operation of the system, distributing power to motors, sensors, and the control unit while ensuring safety through regulation.

Requirements:

- Must supply at least 500mA to the rest of the system continuously at 5V ± 0.1V.
- Must convert 12V power to 3.3V and 5V reliably.

- Must include protection mechanisms such as overcurrent and short circuit protection.

Subsystem 6: Control Unit

Overview:

The control unit, based on the ESP32-WROOM-32E [9] microcontroller, serves as the brain of the system, coordinating all subsystems. It communicates with the color sensing subsystem via I2C, sends control signals to the water dispensing and strip storage subsystems, and transmits processed data to the monitoring subsystem. It also receives input from an override button to allow manual operation if necessary.

Requirements:

- Must interface with all other subsystems to manage operations effectively.
- Must communicate with the color sensing subsystem via I2C and control motors and relays through digital signals.
- Must process and transmit collected data via serial communication to the monitoring subsystem.
- Must support an override button for manual operation in case of system failure.

Tolerance Analysis

One of the most critical aspects of our design is the water dispensing subsystem, which must deliver a precise volume of water to the test strip to ensure consistent chemical reactions. Any deviation beyond ±5% in dispensed water volume could lead to inaccurate chemical concentration readings, resulting in incorrect water quality assessments.

To model the precision of our system, we consider the flow rate equation for fluid dynamics:

$Q=Av$

where:

- Q is the volumetric flow rate (m^3/s),
- A is the cross-sectional area of the nozzle (m^2),
- v is the velocity of the fluid (m/s).

Experimental Validation:

1. We will measure the actual dispensed water mass over multiple cycles using a high-precision scale to determine variability.

2. Using statistical analysis (mean and standard deviation), we will quantify expected water volume dispersion.
3. If deviations exceed the ±5% tolerance, we will adjust solenoid timing or select a better-calibrated nozzle to improve precision.

By combining mathematical modeling and empirical testing, we ensure that the water dispensing subsystem consistently delivers the correct amount of water with minimal variance.

Ethics and Safety

Safety

1. This device is designed to improve water quality monitoring through automation, increasing efficiency and reducing human error. Since it will be relied upon for accurate water testing, it must be built to provide precise and repeatable results. Any inaccuracies in the system could lead to incorrect assessments of water quality, potentially causing harm to users.

2. The ACM Code of Ethics also emphasizes "minimizing negative consequences of computing, including threats to health, safety, personal security." Given that our device involves electronic components interacting with water, we will enforce strict safety measures, such as waterproofing and insulating all electrical elements. Additionally, we will conduct extensive testing to verify thermal and electrical safety and ensure that all components meet regulatory compliance standards.

Ethics

Protecting user data and ensuring transparency is fundamental to our project. Since our system processes water quality data, we will implement security measures to prevent unauthorized access or data misuse. Our vision is to have no data transmitted out of the system onto a network. This will help protect their data and also can help prevent any malicious attacks. The ACM Code of Ethics states that honesty and trustworthiness are critical in product development, and we will uphold these principles by keeping users informed about how the system functions and ensuring full transparency. To promote accessibility, our system will be designed to accommodate users of varying technical expertise, including an intuitive user interface and clear documentation to ensure users can operate the system effectively.

References

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[4] "Drinking Water Test Strips," Amazon, https://www.amazon.com/Water-Testing-Kits-Drinking-Hardness/dp/B0BG63JJ3T (accessed Feb. 12, 2025).

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[7] "4 Phase Stepper Motor, 12V 5-wire stepper motor small reduction stepper motor 28BYJ-48-12V for DIY Project : Electronics," Amazon, https://www.amazon.com/Stepper-5-Wire-Reduction-28BYJ-48-12V-Project/dp/B0CCHW29B4 (accessed Feb. 14, 2025).

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