ECE 445

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Senior Design Project Proposal

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# Water Quality Monitoring System

Group #63

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# 1 Introduction

## 1.1 Problem

Due to water pollution from industrial waste, agricultural runoff, and inadequate infrastructure, maintaining the water quality of water, specifically fish tanks/farms, can be an arduous task. We need to monitor the water quality of freshwater environments such as rivers, lakes, and reservoirs to ensure the safety of ecosystems, specifically fish tanks/farms. Current methods for monitoring water quality often involve manual sampling and lab testing which is time-consuming, expensive, and lacks real-time data. Our project addresses these issues by designing a low-cost, scalable IoT system to monitor water quality parameters in real time.

## 1.2 Solution

We propose an IoT-based water quality monitoring system designed to provide real-time, actionable insights into maintaining water quality. Our solution features a custom PCB that integrates the ESP32 microcontroller, sensors for pH, turbidity, temperature, dissolved oxygen, and power/communication circuits, ensuring a compact and reliable design. The system measures critical water parameters in real time and transmits data wirelessly to a cloud dashboard for remote monitoring. Additionally, the system will be low-cost, portable, and scalable, making it suitable for fish tanks. By combining affordability, real-time data, and ease of use, our solution empowers communities to monitor water quality proactively and prevent contamination risks.

**1.3 Visual Aid**

Figure 1 is a visual overview of our water quality system.

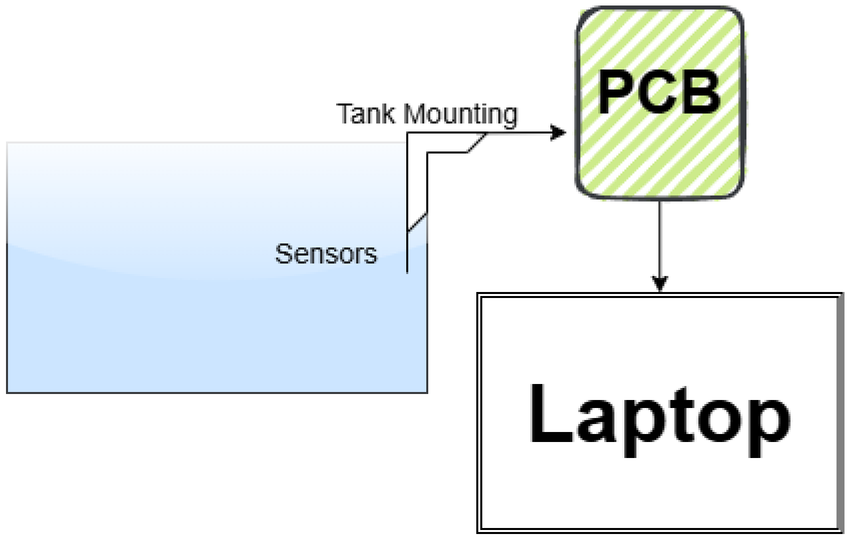


Figure 1: Visual Overview of the Water Quality System

**1.4 High-level requirements list**

- Sensor Accuracy: The system must measure pH, turbidity, temperature, total dissolved solids (TDS), and dissolved oxygen (DO) with an accuracy of within 5% of calibrated lab equipment to ensure reliable water quality assessment.

- Real-Time Data Transmission: The system must transmit sensor data to the cloud every 30 minutes with a packet loss of less than 5%, ensuring continuous and reliable monitoring.

- Sustained Operation: The system must be able to operate for at least 24 hours on battery power while collecting and transmitting data, making it suitable for off-grid and remote deployments.

# 2 Design

## 2.1 Block Diagram

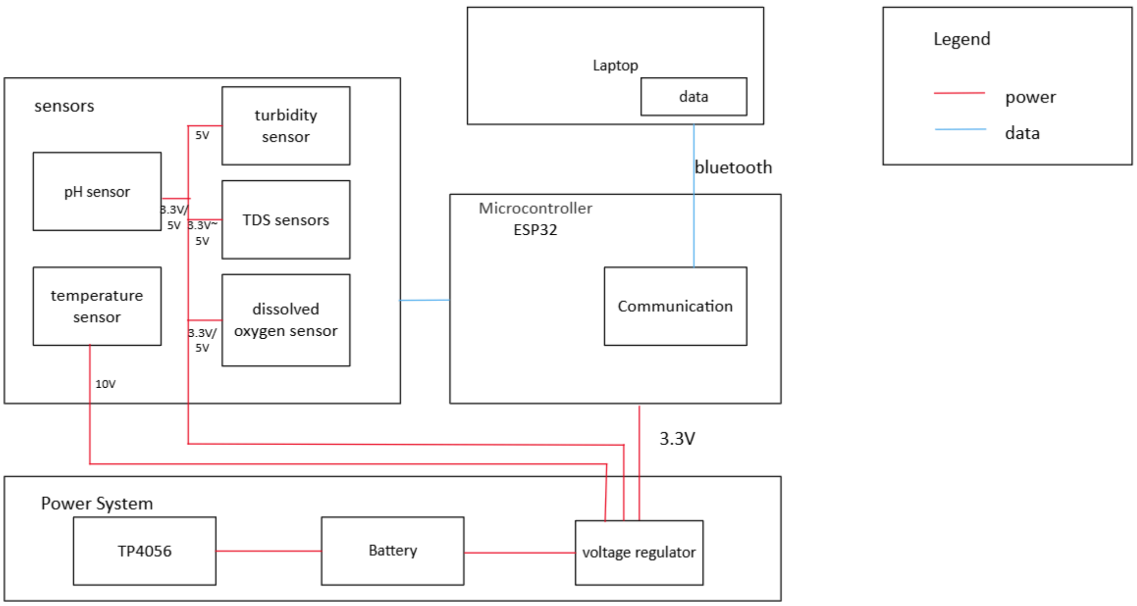


Figure 2: Block Diagram

## 2.2 Subsystem Overview

### 2.2.1 Microcontroller:

ESP32 (QFN package, pre-soldered by lab or ordered from E-Shop). The Microcontroller Subsystem is the core processing unit of the water quality monitoring system, responsible for acquiring, processing, and transmitting sensor data. It collects analog and digital signals from the pH, turbidity, temperature (Digikey 480-2016-ND), and TDS sensors, converting them into digital values using its ADC. It also optimizes power usage for the battery, ensuring efficient operation with the power subsystem. [3]

### 2.2.2 Sensor Array

The Sensor Array Subsystem is responsible for collecting real-time water quality data by measuring key parameters such as pH, turbidity, temperature, dissolved oxygen, and total dissolved solids (TDS). pH Sensor: 5016-SRV-PH-ND, Turbidity Sensor: 1738-1185-ND Liquid

Temp Sensor: Digikey 480-2016-ND (ECE 445 Parts Inventory) TDS Sensor: DigiKey 1738-1368-ND Dissolved oxygen sensor: 5016-EZO-DO-ND

**2.2.3 Communication:**

The Communication Subsystem enables data transmission, remote access, and cloud integration for the water quality monitoring system. This ensures real-time monitoring and data storage for further analysis. ESP32 Built-in Wi-Fi (QFN package). UART Header for Programming (Through-hole pins). IoT Connectivity: ESP32/ESP8266 for Wi-Fi or LoRa module for long-range communication. Cloud Integration: Data sent to AWS IoT/ThingSpeak for storage and analysis.

**2.2.4 Power System**

The Power Subsystem ensures a stable and reliable energy supply for the water quality monitoring system, supporting battery-powered operation: external to PCB, connected via through-hole terminal block, Wide traces for high-current paths. Battery Management: TP4056 Charging Module (through-hole). Voltage Regulator (Through-hole for easy soldering).

**2.3 Subsystem Requirements**

**2.3.1 Microcontroller:**

- Must correctly acquire and process data from all sensors with an accuracy of at least 95%.
- Must be able to handle at least five sensor inputs simultaneously.
- Must support ADC resolution of 12 bits for accurate voltage-to-pH conversion. [3]
- Must transmit data every 30 minutes with less than 5% packet loss.

**2.3.2 Sensor Array:**

- pH Sensor (5016-SRV-PH-ND): Must output a voltage range of 3.00V to 0.265V, converted to pH using the given equation. [7]
- Turbidity Sensor (1738-1185-ND): Must provide a response within 5% error of a reference turbidimeter. [1]
- Temperature Sensor (Digikey 480-2016-ND): Must be accurate to ±0.5°C to ensure proper pH compensation. [4]
- TDS Sensor (1738-1368-ND): Must measure dissolved solids from 0-1000 ppm within 5% accuracy. [2]
- DO Sensor (5016-EZO-DO-ND): Must detect oxygen concentration from 0-100 mg/L within +/– 0.05 mg/L precision. [8]

**2.3.3 Communication:**

- Must establish a bluetooth connection within the laptop application.
- Must transmit data every 30 minutes with packet loss below 5%.
- Must support UART for debugging and external programming.
- Must be able to store data locally in case of connectivity failure and retry transmission.

**2.3.4 Power System:**

- The voltage regulator must supply at least 500mA continuously at 0 ~ 10V to power the entire system.
- The TP4056 module must prevent overcharging and deep discharge of the battery. [6]
- The system must operate for at least 24 hours on a fully charged battery.

**2.4 Tolerance Analysis**

One of the most critical aspects of our water quality monitoring system is the accuracy and stability of sensor readings, particularly for pH, turbidity, and dissolved oxygen (DO) sensors. Ensuring these sensors operate within an acceptable error margin (≤5%) is crucial for reliable water quality assessment.

For the pH sensor 5016-SRV-PH-ND, factors such as temperature variations, ADC resolution, and electrical noise could introduce errors in pH measurements, impacting overall system reliability. The sensor will output a voltage from 3.00V to 0.265V. [7] We use Equation 1 below to convert voltage to pH value:

$$pH = (-5.6548 \times voltage) + 15.509 \tag{1}$$

This process can be done in the ESP32 microcontroller. When reading analog voltage from the sensor, the microcontroller will apply this equation to determine the pH value accurately. The ESP32 features a 12-bit ADC, meaning it can represent values from 0 to 4095. [3] Given a 3.3V reference voltage, the smallest detectable voltage change is:

$$\frac{3.3v}{4096} \approx 0.0008V \tag{2}$$

Then, using equation 2, the corresponding pH resolution is:

$$\Delta pH = -5.6548 \times 0.0008 \approx 0.0045 \tag{3}$$

Equation 3 suggests that the ESP32 can resolve pH changes as small as 0.0045, ensuring sufficient precision within the 5% accuracy requirement. In addition, temperature can also have an effect on the accuracy of pH measurements. The pH sensor's output varies with temperature. To mitigate this, we will integrate a temperature compensation algorithm using the temperature sensor. Furthermore, external noise may introduce errors. To reduce electrical noise, we can average over multiple samples to smooth fluctuations, and we can apply low-pass filtering to remove high-frequency noise. Regular calibration using standard pH buffers (pH 4, 7, and 10) [7] will ensure the system maintains accuracy within the 5% error tolerance.

# 3 Ethics and Safety

### 3.1 Ethics

Our IoT-based water quality monitoring system prioritizes ethical responsibility and safety to ensure secure, reliable, and environmentally conscious operation. We will mainly follow IEEE Code of Ethics adopted by the IEEE Board of Directors through June 2020 [5]. Guided by the IEEE Code of Ethics, we prioritize the following principles:

1. **Transparency and Accountability [5]**
   We uphold transparency by openly sharing the water quality system's methodologies, capabilities, and limitations with users. This ensures informed decision-making and fosters trust. Any potential biases in the system's performance will be addressed through rigorous testing with diverse water samples, ensuring equitable and reliable outcomes across different environments.
2. **Data Privacy and Security [5]**
   Protecting user data is an important part of our ethical framework. All water quality data collected will be securely stored and transmitted using encryption and other robust cybersecurity measures to prevent unauthorized access. We will adhere to data protection regulations and ensure that users retain control over their information.
3. **Fairness and Inclusivity [5]**
   The system is designed to be accessible and beneficial to all users, regardless of technical expertise or geographic location.
4. **Responsible Innovation [5]**
   We recognize the potential societal and environmental impacts of technological advancements. Our water quality system will be developed and deployed with careful consideration of its long-term effects, ensuring that it does not inadvertently harm

communities or ecosystems. We will actively seek feedback from stakeholders to improve the system and address emerging ethical concerns.

5. **Professional Integrity [5]**
   As developers and engineers, we commit to maintaining the highest standards of honesty, integrity, and professionalism. We will avoid conflicts of interest, provide accurate and unbiased information, and ensure that our work is free from misrepresentation or misuse.

**3.2 Safety**

Data privacy and security are key concerns, so all collected water quality data will be securely stored and transmitted to prevent unauthorized access. The system's transparency is maintained by clearly stating its limitations and providing open access to methodologies, ensuring users understand its capabilities and accuracy constraints. To prevent bias, the system will be validated with diverse water samples to ensure reliable performance across different environments. Electrical safety is addressed through proper insulation, waterproofing, and the use of low-voltage components, reducing risks of short circuits or electric shock. Additionally, the materials used in our sensors will be non-toxic and safe for aquatic environments, preventing contamination. Our design minimizes environmental impact by using modular, repairable components and providing clear disposal instructions for batteries and electronic waste. System reliability is critical, so measures such as alert mechanisms for sensor malfunctions and guidelines for proper maintenance will be implemented to prevent false readings that could lead to incorrect decisions. Finally, the system will be designed for ease of use, ensuring that installation does not require technical expertise while mitigating risks associated with misuse or extreme environmental conditions. By addressing these ethical and safety concerns, our project aims to provide a responsible, user-friendly, and effective solution for real-time water quality monitoring.

# 4 References

[1] Dfrobot. “”Turbidity Sensor SKU: Sen0189”.” (2017). [Online]. Available: https://mm.digikey.com/Volume0/opasdata/d220001/medias/docus/2555/SEN0189_Web.pdf (visited on 02/12/2025)

[2] Dfrobot. “”Gravity: Analog TDS Sensor / Meter For Arduino  SKU: SEN0244”.” (n.d). [Online]. Available: https://mm.digikey.com/Volume0/opasdata/d220001/medias/docus/2309/SEN0244_Web.pdf (visited on 02/12/2025)

[3] Espressif. “”ESP32 Series Datasheet Version 4.8“.” (2025). [Online]. Available: https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf (visited on 02/12/2025)

[4] Honeywell. “”Temperature Sensors”.” (2001). [Online]. Available: https://mm.digikey.com/Volume0/opasdata/d220001/medias/docus/4845/DS_1482_TD%20Series.pdf (visited on 02/12/2025)

[5] IEEE. “”IEEE Code of Ethics”.” (2016), [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html (visited on 02/13/2025).

[6] NanJing Top Power ASIC Corp. “”TP4056 1A Standalone Linear Li-lon Battery Charger with Thermal Regulation in SOP-8”.” (n.d). [Online]. https://dlnmh9ip6v2uc.cloudfront.net/datasheets/Prototyping/TP4056.pdf (visited on 02/12/2025)

[7] Press, J., & Press, N. ““Analog PH sensor / meter - atlas scientific”.” (2024), [Online]. Available: https://files.atlas-scientific.com/Gravity-pH-datasheet.pdf (visited on 02/12/2025)

[8] Press, J., & Press, N. ““EZO-DO Embedded Dissolved Oxygen Circuit - atlas scientific”.” (2024), [Online]. Available: https://files.atlas-scientific.com/DO_EZO_Datasheet.pdf (visited on 02/12/2025)