ECE 445
Senior Design Lab
Design Document

AquaSense: Affordable ML-Based Water Quality Monitoring for Aquariums

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Table of Contents

Abstract

AquaSense is an affordable water quality monitoring system aimed at aquarium owners. It continuously measures three key parameters quantifying aquarium health: pH, temperature, and dissolved oxygen via an ESP32 microcontroller. The system wirelessly transmits parsed real-time data into a cloud-powered mobile dashboard feed, empowering users to monitor trends in water quality and receive alerts when conditions fall outside preferred ranges specific to their aquarium. Additionally, Machine Learning algorithms can analyze historical user-specific data to detect anomalies and predict trends in water quality issues. With this emphasis on affordability, accuracy, intelligence, and consumer-facing design, AquaSense provides a unique and accessible solution for maintaining a healthy aquatic environment with minimal hassle for the owner.

1 Introduction

1.1 Problem

As an aquarium owner, you may have experienced the anxiety of leaving your fish unattended for an extended period — whether for work, travel, or vacation — without knowing if water conditions remain safe. Imperfect aquarium conditions can quickly deteriorate, leading to illness or even fatal consequences for fish and aquatic plants. Maintaining optimal water quality is therefore crucial for the health of aquatic organisms; poor water quality is a leading cause of illness in fish, and maintaining proper water parameters is essential for their well-being [1]. However, many hobbyists and small-scale fishkeepers lack access to affordable, real-time water monitoring solutions. Traditional testing methods involve manual kits that require frequent intervention, making it difficult to detect rapid fluctuations in parameters such as pH, temperature, or dissolved oxygen, which can be harmful to fish and aquatic plants [2].

Existing automated water quality monitoring solutions are often expensive and designed for industrial-scale applications, leaving home aquarium owners with few accessible options. For instance, advanced monitoring systems are tailored for large-scale aquaculture operations and may not be cost-effective for individual hobbyists [3]. To bridge this gap, there is a need for a low-cost, plug-and-play solution that continuously monitors water conditions and provides real-time alerts when the water quality becomes unsuitable for fish. Such a system would enable aquarium enthusiasts to maintain healthier environments for their aquatic life.

One example of an affordable monitoring device is the Kactoily Smart 7-in-1 Aquarium Monitor, which offers real-time water quality tracking with built-in Wi-Fi, allowing users to oversee parameters such as pH and temperature continuously [4]. Implementing accessible monitoring solutions can significantly enhance the ability of hobbyists to maintain optimal water conditions, thereby promoting the health and longevity of their aquatic organisms.

1.2 Solution

We propose AquaSense, a cost-effective, ESP32-based plug-and-play PCB designed to provide real-time water quality monitoring for aquarium owners. This compact system integrates multiple sensors to continuously track key water parameters, including pH, temperature, and dissolved oxygen, ensuring a healthier and more stable aquatic environment. By leveraging the ESP32 microcontroller, AquaSense offers seamless Wi-Fi and Bluetooth connectivity, allowing users to remotely monitor water conditions via a web-based dashboard with real-time data logging, trend analysis, and historical insights. Our solution is structured into two primary components: the sensing system and the monitoring interface.

- The sensing system consists of precision pH, temperature, and dissolved oxygen sensors that are strategically placed within the aquarium to ensure accurate, real-time data collection. These sensors transmit their readings to the ESP32 microcontroller, which processes the data and relays it to the user interface.
- The monitoring interface provides users with an intuitive web dashboard, built with React, that offers a comprehensive view of the water conditions. Users can track real-time water quality, view historical trends, and receive detailed insights into the overall health of their aquarium.

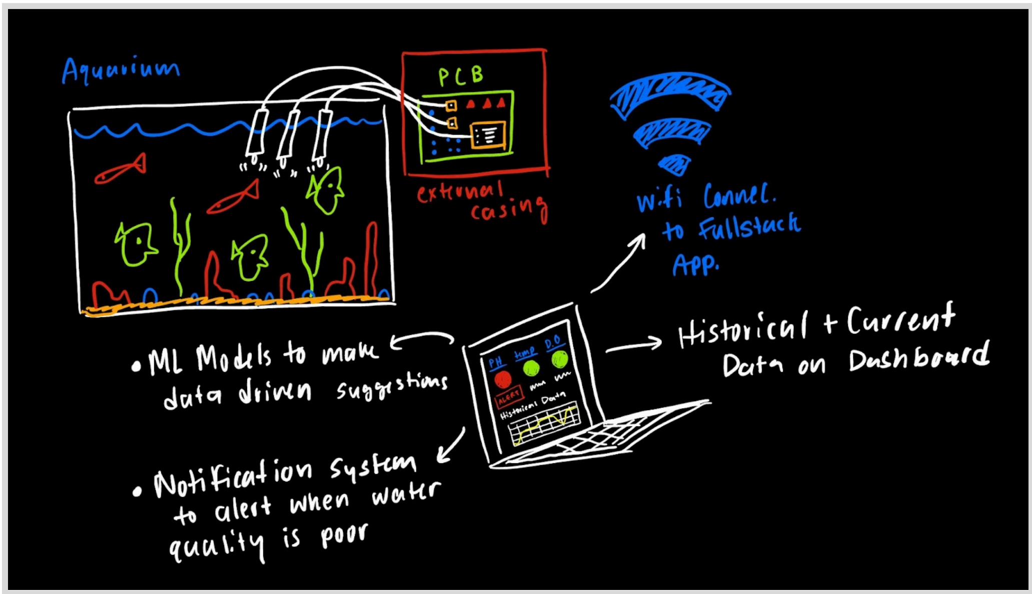
AquaSense features an automated alert system that notifies users through mobile push notifications and email alerts whenever water parameters deviate from predefined safe ranges. This system ensures timely intervention to prevent harmful fluctuations that could threaten aquatic life. Users can customize threshold levels based on their specific aquarium needs, making the system adaptable to various setups, from freshwater to saltwater tanks.

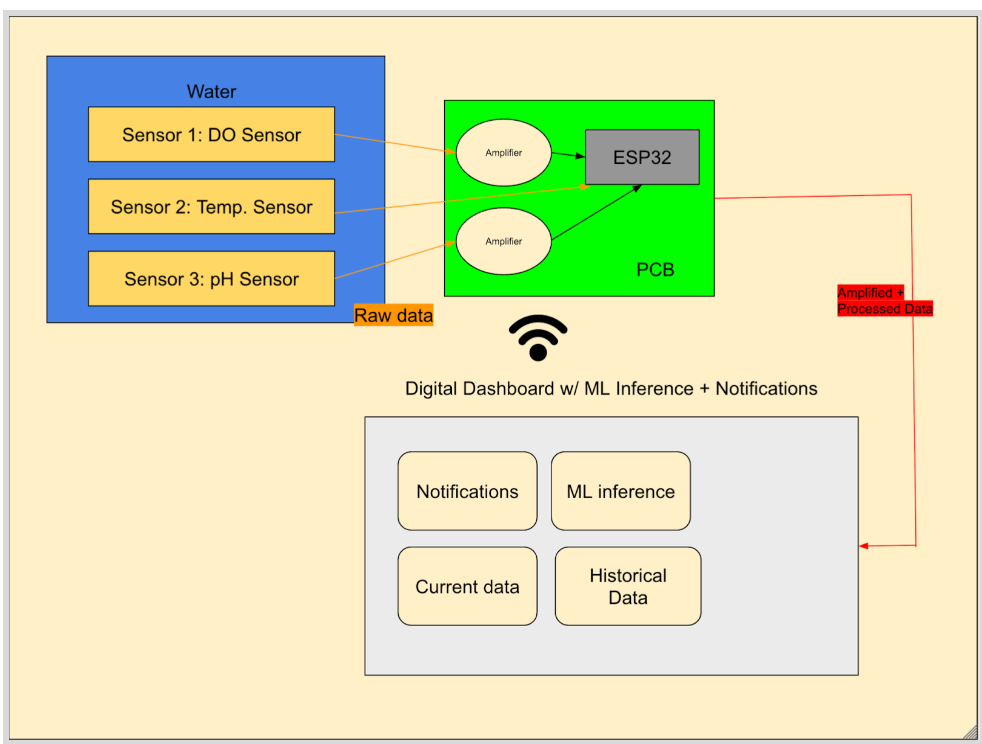
To maximize accessibility, AquaSense is designed as a plug-and-play device requiring minimal setup. It is optimized for low-power consumption, ensuring continuous operation without frequent maintenance. The ESP32's Bluetooth Low Energy (BLE) capability enables local connectivity, allowing users to check water conditions even in environments with limited Wi-Fi access.

Consider a scenario where AquaSense detects a pH drop from 7.5 to 6.8 in a saltwater aquarium. The system immediately alerts the user, enabling corrective action before the change becomes harmful. If dissolved oxygen levels drop, the system can suggest increasing aeration or adjusting water flow. By leveraging data-driven insights, AquaSense empowers users to maintain optimal conditions proactively, reducing stress on aquatic life and enhancing long-term tank stability.

By integrating real-time monitoring, remote access, automated alerts, and customizable settings, AquaSense offers an affordable, precise, and user-friendly solution for aquarium enthusiasts. Whether for casual hobbyists or dedicated aquarists, AquaSense provides peace of mind by ensuring that aquarium water conditions are continuously monitored and optimized for the health and well-being of aquatic life.

1.3 Visual Aid





1.4 High-Level Requirements

For our project to be considered a success, we should aim to satisfy the following:

HLR-1: Continuous Monitoring of Critical Water Quality Parameters

To maintain an optimal aquatic environment, AquaSense must perform real-time, high resolution monitoring of water pH, temperature, and dissolved oxygen—parameters that critically influence fish metabolism, immune response, and overall biotic stability. The system shall capture and log readings at 5 to 10 second intervals to detect transient perturbations that could otherwise be missed by manual or infrequent testing methods. Each sensor must operate within stringent accuracy tolerances—±0.2 pH, ±0.5°C, and ±0.5 mg/L respectively—to allow for proper analysis of aquarium conditions.

HLR-2: Wireless Data Transmission and Real-Time Alerts

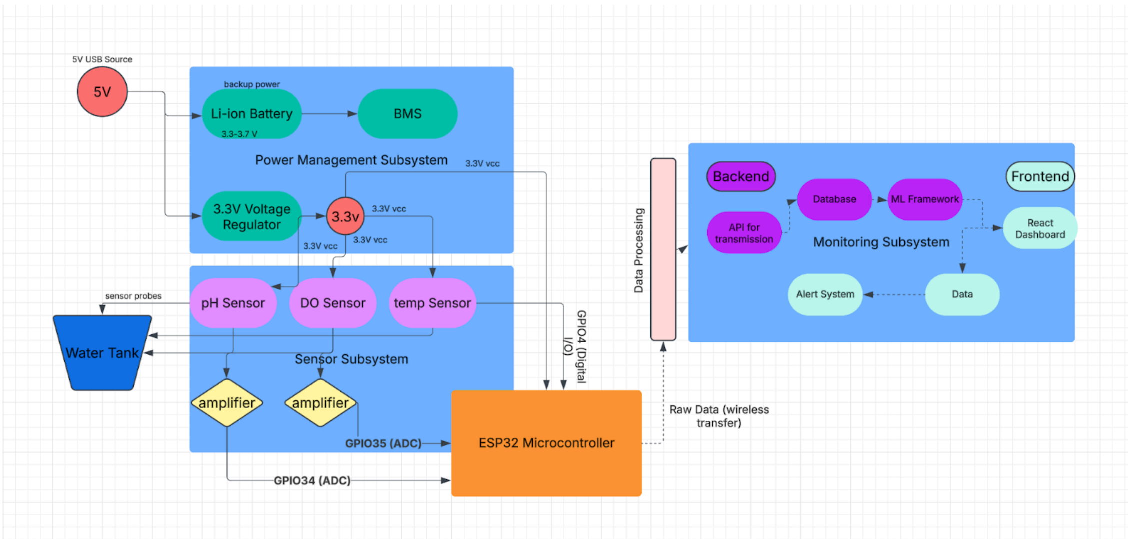
AquaSense should be able to communicate data and analysis to the user via Wi-Fi and Bluetooth through a secure, cloud based dashboard in real-time. The system must support live updates at intervals of 10-15 seconds, ensuring that potential rapid changes in aquatic conditions (sudden temperature drops or pH spikes) are made aware early on. The user can configure thresholds based on the specific biotic needs of their aquarium, and AquaSense will alert them accordingly via push notifications or email. These alerts will be paired with intelligent suggestions for the user (ex. *"-- pH levels low… consider performing a partial (25%) water change --"*).

HLR-3: Automated Water Quality Trend Analysis and Machine Learning–Based Anomaly Detection

To formulate aforementioned alert suggestions, AquaSense will leverage machine learning to detect patterns (anomaly detection) and proactively alert users to potential water quality risks. The model will be trained on the user's own historical data of sensor readings over time and paired with a fine-tuned LLM to craft responses with high-quality semantics and the greatest possible level of personalization.

2 Design

2.1 Block Diagram



2.2 Subsystem Overview

2.2.1 Power Management Subsystem (Hardware)

The Power Management Subsystem is responsible for supplying stable and efficient power to the entire AquaSense device, ensuring uninterrupted operation whether it is plugged into a 5V USB source or running on battery power. This subsystem incorporates voltage regulators to maintain consistent output levels under varying input conditions, enabling sensitive sensors and the ESP32 microcontroller to perform accurately. When operating on battery, the subsystem should support continuous monitoring for extended periods—up to 30 days on a 5,000 mAh lithium-ion battery—by leveraging a low-power standby mode. This mode conserves energy by allowing the ESP32 to switch into a reduced consumption state when water parameters remain stable, yet it can instantly wake the system if an abnormal reading is detected. Robust power design is thus paramount to satisfy both short-term operational demands and long-term reliability targets outlined in HLR-4 (Energy Efficiency and Hardware Longevity).

2.2.2 Sensor Subsystem (Hardware)

The Sensor Subsystem acquires three primary water quality parameters—pH, temperature, and dissolved oxygen—that are essential for monitoring aquarium health. It uses a SEN0161 pH Sensor to measure acidity or alkalinity with ±0.2 pH unit accuracy, a DS18B20 Digital Temperature Sensor to read water temperature with ±0.5°C precision, and a DFRobot Gravity Dissolved Oxygen Sensor to detect oxygen levels within ±0.5 mg/L. These sensors connect to the ESP32 microcontroller, which gathers data at 5–10-second intervals. The Sensor Subsystem may also include an Analog Turbidity Sensor if extended clarity monitoring is required. Once collected, the readings are validated, logged, and broadcast via Wi-Fi or Bluetooth, ensuring near-instant alerts if parameters exceed user-defined thresholds.

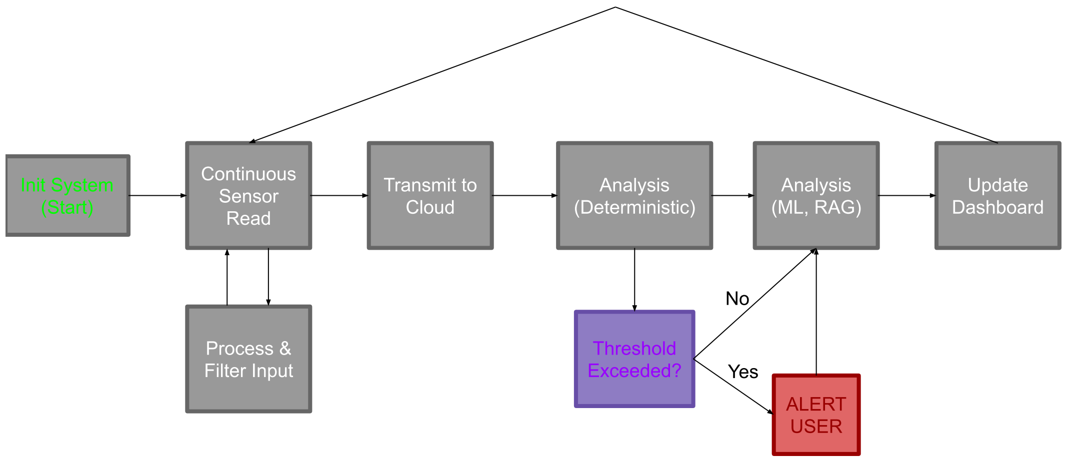
2.2.3 System Monitor (Software)

The System Monitor is a full-stack solution comprising a Node.js backend and a React.js frontend. It stores historical readings, enforces configurable alert thresholds, and presents data through a dynamic dashboard. Users can view real-time graphs of pH, temperature, and dissolved oxygen, as well as any optional turbidity readings. For multi-location installations, a map-based interface (using the Google Maps API) displays the status of each AquaSense node. This subsystem supports anomaly detection by applying machine learning and statistical methods to the stored sensor data. When sensor readings dip outside of the set ideal range, the System Monitor triggers immediate notifications and logs the event for deeper analysis in the form of a Recommendation System.

There are two stages to the analysis of the data. First, deterministic logic is applied to the raw sensor readings, pre-processed from [V] into the correct units (pH, degrees, mg/L). If the readings lie outside the preset range, its metadata (timestamp, magnitude, sign, units, z-score) is computed and logged as an event (datapoint) to be fed to the statistical models and the deep model (LLM). Random Forests will be used, along with XGBoost, to learn patterns and previous system states upon which the most notable and extreme behaviors occur.

The second stage of the analysis is performed using the previously collected event data. But instead of performing statistical analysis, we use it as part of a retrieval-augmented generation scheme to query a Hugging Face LLM and obtain an intelligent response. For example, if the pH level sees a drastic drop, an automated query can be made: “Why is my pH dropping so fast?”, and paired with user historical data, we can obtain an expert response—effectively harnessing modern Large Language Model architecture and knowledge for our aquatic purposes.

The Recommendation System algorithm has the following state machine:



It illustrates the cyclical, continuous nature of the system.

2.3 Requirements and Verification Table

Requirements	Verification
• Power Management Subsystem (1): must maintain constant 5V supply, preventing voltage drops that compromise the accuracy of sensors or disrupt the ESP32. Active mode power consumption must remain below 1.5W, transitioning to under 0.5W in standby.	• Use multimeter to measure the ESP32's input voltage while system is in active mode.
• Power Management Subsystem (2): When using a 5,000 mAh battery, it should operate continuously for at least 30 days without user intervention.	• Charge a fully depleted 5000 [mAh] battery, and connect it. Run the system and exercise each part of the State machine (including Wi-Fi transmission etc), then track battery life
• Power Management Subsystem (3): Tests must confirm that the system transitions seamlessly between active and standby modes, while ensuring consistent output voltage under varying load conditions and real-world aquarium environments.	• Place setup in room-temperature setting, comfortable aquatic temperature (room temperature) and record power draw in active mode. Use an oscilloscope to verify the system transitions without power spikes/interruptions.

• Sensor Subsystem (1): Must capture and transmit pH, temperature, and dissolved oxygen readings every 5–10 seconds.	• Use a timer to time intervals between transmissions shown on the microcontroller.
• Sensor Subsystem (2): It must maintain ±0.2 accuracy for pH, ±0.5°C for temperature, and ±0.5 mg/L for dissolved oxygen for at least 60 days without recalibration.	• Calibrate each sensor using known reference water solutions: commercial pH buffer solutions, microwaved water with thermometer, and kitchen whisk added to microwaved water (eliminates oxygen levels).
• Sensor Subsystem (3): Alerts must be issued within 2 seconds of detecting values outside predefined thresholds, aligning with the system's real-time monitoring objective.	• Use a timer to verify the latency of the system response.
• Sensor Subsystem (4): Due to the nature of the sensors and their inherent need for waterproofing, the raw probes are highly sensitive. The system must adequately transform weak raw probe readings into a voltage level compatible with the microcontroller, via signal conditioning.	• Use an oscilloscope to measure the readings and verify they are fit for transmission to ESP32 (max 3.3 [V]), testing at extreme solutions (commercial pH, hot water, kitchen whisk).
• System Monitor Subsystem (1): Must display real-time sensor values at 10-second intervals or less, with an end-to-end latency of under 2 seconds from measurement to dashboard update.	• Simulate sensor readings by creating artificial data and transmitting it to test wireless latency.
• System Monitor Subsystem (2): Data logging must capture at least 1,000 data points per parameter over a 30-day rolling window, enabling machine learning or statistical algorithms to detect anomalies that exceed three standard deviations from the mean.	• Store test sensor data in the cloud DB for 30 days

• System Monitor Subsystem (3): These algorithms must achieve at least 90% accuracy in identifying critical events such as heater failures or oxygen depletion.	• Simulate known failures, like extremely high temperatures and oxygen density levels.
• System Monitor Subsystem (4): Performance tests must confirm rapid data retrieval, reliable alert distribution, and intuitive navigation under typical home or light-commercial networking conditions.	• Spin up many virtual machines to simulate a high-traffic environment streaming data, and measure how long it takes a user to receive an alert after an anomaly occurs.

2.7 Tolerance Analysis

Each sensor must operate within reasonable accuracy tolerances in order to maintain adequately healthy environments for fish to thrive. In particular, the sensor readings should reflect and communicate to the user in a "hands-free" way that recommends simple and easy-to-follow steps to improve aquarium vitals upon detecting imperfect conditions.

To start, in regards to the acidity levels, the diversity of fish species leads to a rather specific hierarchy of pH tolerances:

pH Sensitivity [pH]	Fish species
5.5-6.5	Angelfish, Betta, Cardinal Tetra, Discus
6.5-7.0	Corydoras Catfish, Gouramis, Neon Tetra
7.0-7.5	Guppy, Molly, Swordtail, Zebrafish
7.5-8.5	Goldfish, African Cichlid, Live

Temperature and acidity have a direct interplay due to the nature of the pH sensor. It follows that temperature is yet another variable that must be added to the equation for computing the safety level displayed by the mobile app. To compensate for voltage output of the pH probe changing with temperature, we use 25°C as a pivot to adjust our granularity denominator when normalizing our acidity sensor voltage reading into pH level:

$pH_{final} = \frac{(E_0 - V)}{V/pH}$, where $V/pH = 0.05916 \times \frac{T_{Kelvin}}{298.15}$

Temperature can also have an adverse effect on varying fish species, albeit less stringent (they can adapt, slowly, to temperature changes but sudden shifts may hurt their metabolism and immune responses):

Dissolved Oxygen [°C]	Fish species
0-18	Goldfish, Carp, Trout, Salmon, Koi
18-28	Betta, Guppy, Molly, Swordtail, Tetra, Neon Tetra, Gouramis, Angelfish, Zebra, Catfish
28-32	Discus, African Cichlid

For oxygen, as stated earlier—±0.5 mg/L accuracy is desired. Fish diversity is also of utmost concern here, because low DO can cause suffocation, while high DO may cause gas bubble disease:

Dissolved Oxygen [mg/L]	Fish species
2.0-4.0	Goldfish, Catfish, Carp
4.0-6.0	Guppy, Betta, Molly, Swordtail
6.0-8.0	Tetra, Gouramis, Angelfish, Discus
8.0-12.0	Salmon, Trout, Zebra

The system should also support accurate readings with a minimum specificity to adhere to the ranges listed above. Whether or not our system is capable of delivering on this front depends on the measurement accuracy of the sensor (how correct the measured value is compared to the true value) and the precision of the analog-to-digital resolution of the microcontroller interfacing the sensor. The sensor kits should have accuracy of ±0.1 [pH] within a reasonable temperature range (around 25°C). To ensure this accuracy is not being bottlenecked, we can perform a granularity analysis of the ESP32 ADC using the Nernst equation:

$$E = E_0 - (\frac{RT}{F})ln(|H^+|)$$

From here, we can extract the relationship between voltage and pH:

$V/pH = (0.025692) \times (2.303) =$ +0.05916 [V] change in voltage per +1.0 [pH].

ADC_Res_{STM32} = 12-bit = $2^{12} = 4096$ levels

STM32 operating voltage: 3.6 [V]

Voltage per ADC step: $\frac{3.6}{4096} = 0.00087890625$ [V]

Granularity: $\frac{0.00087890625\ [V}{0.05916\ [V]} = 0.0148564275$

Our system should theoretically be able to support a precision of nearly 0.01—10 times the sensor accuracy.

3 Cost, Schedule and Risk Analysis

3.1 Parts Analysis

The total cost for parts as seen below before shipping is $164.07. A 5% shipping cost adds another $8.20, and 10% sales tax adds another $16.41. We can expect a salary of $40/hr × 2.5 hr × 60 weeks = $6000 per team member. Since we have three team members, the total labor cost amounts to $18,000. This results in a total project cost of $18,188.68.

Description	Manufacturer	Item #	Quantity	Price	Link
ESP32-WROOM-32	Espressif Systems	ESP32-WROOM-32	1	$3.00	link
SEN0161 pH Sensor	DFRobot	SEN0161	1	$29.50	link
DS18B20 Digital Temperature Sensor	Maxim Integrated	DS18B20	1	$6.00	link
DFRobot Gravity Dissolved Oxygen Sensor	DFRobot	SEN0237	1	$11.80	link
Analog Turbidity Sensor SEN0189	DFRobot	SEN0189	1	$9.90	link
Op-Amp: UA741CP	Texas Instruments	UA741CP	1	$0.50	link
LM4041 Precision Voltage Reference	Texas Instruments	LM4041	2	$0.50	link
TLA431 Adjustable Shunt Regulator	Texas Instruments	TLA431	2	$0.50	link
VLD1117V33 Voltage Regulator 3.3V	STMicroelectronics	VLD1117V33	1	$8.99	link
Fish Tank	Aqueon	100528594	1	$50.90	link
Fish Food (Tropical Flakes)	Tetra	16150	1	$5.50	link
Resistors	Vishay / Yageo	150-piece kit	1	$10.50	link
5mm LED Diodes Kit	Chanzon	B07W8DGBVF	1	$8.50	link
Buzzer 5V	Adafruit	1536	1	$3.99	link

(Piezoelectric)					
Lithium Battery	Panasonic	NCR18650B	1	$12.99	link

Figure __ Itemized list of Components and Costs

3.2 Schedule (Time Table)

Week	Tasks	Person Responsible
February 21st - February 28th	Order all essential components for AquaSense prototyping (ESP32, sensors, power modules, etc.)	Everyone
	Begin PCB design for sensor integration and wireless communication	Everyone
	Develop initial firmware for ESP32 to read sensor data and transmit wirelessly	Everyone
	Research machine learning models for anomaly detection in water quality trends	Everyone
February 28th - March 7th	Assemble and test individual sensor modules (pH, temperature, dissolved oxygen)	Michael
	Design and 3D-print waterproof sensor housing for optimal placement in the aquarium	Anurag
	Implement initial wireless communication between ESP32 and cloud dashboard	Arnav
	Refine BOM (Bill of Materials) and place final component orders	Everyone
March 7th - March 14th	Complete full hardware prototype assembly and perform preliminary testing	Everyone
	Develop and test anomaly detection model using sample sensor data	Michael
	Integrate machine learning model with the cloud dashboard for real-time insights	Anurag

	Optimize power efficiency of the system, ensuring long battery life	Arnav
March 14th - March 21st	Refine microcontroller firmware and establish stable sensor-to-cloud data transmission	Michael
	Conduct thorough stress testing on sensors in different water conditions	Anurag
	Finalize first iteration of the mobile dashboard UI with real-time data visualization	Arnav
	PCB ORDER MARCH 18TH	Everyone
March 22nd - March 28th	Assemble and test the first batch of PCBs for functionality and reliability	Everyone
	Implement real-time alert system for water quality deviations via mobile notifications	Michael
	Conduct full system test: sensor data collection → cloud transmission → anomaly detection → alerts	Anurag
	Improve physical housing based on initial prototype feedback	Arnav
March 28th - April 4th	Integrate battery monitoring and power management circuits	Everyone
	Conduct user testing with aquarium owners to gather feedback on usability	Everyone
	PCB ORDER MARCH 28TH	Everyone
April 4th - April 11th	Finalize software optimizations for sensor calibration and accuracy	Michael
	Perform end-to-end validation and debugging of data pipeline	Anurag
	Conduct final integration tests and ensure system robustness	Arnav
	PCB ORDER APRIL 5TH	Everyone
April 11th -	Address any last-minute bugs and finalize	Everyone

April 18th	documentation	
April 19th	Final project demo and presentation	Everyone

3.3 Risk Analysis

AquaSense is built to help aquarium owners maintain a stable aquatic environment, but like any system, it comes with potential risks. If the pH, temperature, or dissolved oxygen sensors malfunction or provide inaccurate readings, harmful water conditions could go undetected, putting fish and plants at risk. To prevent this, we've included redundant sensor checks, self -calibration routines, and data logging to track performance over time. Another key concern is wireless transmission failures, which could delay alerts from reaching users. To work around this, AquaSense stores data locally when the connection drops and syncs it once the network is restored. We also plan to build in backup connectivity options like Bluetooth and multiple alert methods, including push notifications, email, and LED indicators, to make sure users stay informed. With these safeguards in place, AquaSense is designed to be a reliable and responsive monitoring system, helping aquarium owners catch water quality issues before they become serious problems.

4 Ethics & Safety

Our team adheres to the IEEE Code of Ethics, as adopted by the IEEE Board of Directors in June 2020 [6], recognizing that the technology we create has a real impact on people's lives. As we develop AquaSense, we are committed to maintaining the highest ethical standards, ensuring that our system is both reliable and safe for users. We take responsibility for designing a product that provides accurate, trustworthy data, allowing aquarium owners to make informed decisions about the health of their aquatic ecosystems.

One of our key ethical considerations is data integrity and transparency. Since AquaSense continuously monitors and logs water conditions, it is crucial that users can rely on the readings it provides. We aim to prevent false or misleading sensor outputs by achieving high tolerance levels through high-quality components, regular calibration reminders, and thorough testing to verify accuracy. Users will also have access to clear documentation on how the system works, including its limitations, so they can understand what to expect. Our goal is to provide honest, practical information rather than overpromising performance.

We are also mindful of user privacy and security, particularly since AquaSense transmits data via Wi-Fi and Bluetooth. To ensure that user data remains protected, we will implement basic encryption for wireless communication and provide secure authentication for remote access.

While AquaSense is not handling personal or financial information, we still believe it's important to take precautions against unauthorized access or tampering.

On the safety side, we are designing AquaSense with electrical and environmental protection in mind. Because this system operates near water, we will take steps to waterproof exposed components and insulate electrical connections to prevent short circuits or accidental damage. The power system will be designed to prevent overheating and will include fuse protection to reduce the risk of malfunctions. Additionally, if a battery-powered version is implemented, we will ensure that it operates efficiently and safely over long periods.

Beyond technical and safety concerns, we also care about making technology accessible. Many existing water monitoring solutions are too expensive for casual aquarium owners, and we want to provide a low-cost, user-friendly alternative. By keeping AquaSense affordable and easy to use, we hope to help more people maintain healthy aquatic environments, whether they are hobbyists, educators, or researchers.

Ultimately, we believe that technology should be practical, safe, and built with responsibility. By following ethical engineering practices, prioritizing accuracy, and ensuring user safety, we aim to create a product that people can trust and benefit from without unnecessary risks.

5 Future Developments

Building on its core architecture, AquaSense holds significant potential to evolve into a robust, scalable IoT platform for both home and commercial aquariums. A key avenue of growth involves AI-based predictive analytics, enabling more sophisticated trend detection and forecasting of water parameters over extended time periods. By leveraging these advanced models, AquaSense could proactively signal emerging threats—such as gradual ammonia buildup or nitrate spikes—well before they reach critical levels, thus facilitating timely interventions. Further enhancements may include automated filtration control, allowing the system to autonomously initiate water changes or adjust filtration settings when specific thresholds are breached. An expanded sensor suite could integrate ammonia and nitrate probes, offering a comprehensive view of water chemistry and supporting more precise ecosystem management. Additionally, a battery-powered variant would extend the platform's usability to outdoor ponds, fish farms, and remote applications, ensuring continuous monitoring under off-grid conditions. Beyond benefiting aquarium owners, such expansions would also serve educators, researchers, and environmental conservationists, fostering a broader community dedicated to maintaining stable, thriving aquatic environments.

References:

[1] King British, "Why is water quality such a big issue when it comes to fishkeeping?" [Online]. Available: https://www.kingbritish.co.uk/blog/2020/09/why-is-water-quality-such-a-big-issue-when-it-comes-to-fishkeeping
[2] Pets in the Classroom, "Aquarium Water Quality Curriculum." [Online]. Available: https://www.petsintheclassroom.org/wp-content/uploads/2017/11/Aquarium-Water-Quality-Curriculum.pdf
[3] Wikipedia, "Recirculating aquaculture system." [Online]. Available: https://en.wikipedia.org/wiki/Recirculating_aquaculture_system
[4] YouTube, "Kactoily Smart 7-in-1 Aquarium Monitor," [Online]. Available: https://m.youtube.com/watch?t=0s&v=_z2lzHZdzT0

Add references for sensors, cloud apis, ml, previous aquarium projects

- Sensors can’t have their boards as part of final pcb