

The Implementation of IoT enabled, AI Driven Water Quality Monitoring and Controlling System for Aquaculture

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Abstract: In this paper, we describe about the design of an IoT-enabled, AI-driven water quality monitoring and control system for aquaculture. Maintaining optimal water conditions is essential for healthy aquatic ecosystems and sustainable food production. The system uses sensors to measure key parameters such as temperature, pH, turbidity, total dissolved solids (TDS), and ammonia levels. These sensors are integrated with Arduino Uno and ESP32 microcontrollers, which collect and transmit real-time data to a cloud platform for storage, visualization, and remote access. An AI model analyzes the data to detect anomalies, identify trends, and predict potential water quality issues. When abnormal conditions occur, the system generates instant alerts and classifies water quality into safe, warning, or critical levels using visual indicators. This enables faster decision-making and reduces the need for manual monitoring. Overall, the system improves efficiency, supports sustainable aquaculture practices, and helps ensure better environmental and production outcomes.

Keywords: IoT, Aquaculture, Water Quality Monitoring, Artificial Intelligence, Real-Time Monitoring.

I. INTRODUCTION

Aquaculture has become one of the fastest growing food production sectors, playing a crucial role in meeting the increasing global demand for fish and other aquatic resources. However, the success and sustainability of aquaculture systems largely depend on maintaining optimal water quality conditions. Variations in parameters such as temperature, pH, turbidity, total dissolved solids (TDS), and ammonia levels can significantly affect aquatic life, leading to stress, disease outbreaks, or even mass mortality if not properly managed. Traditional water quality monitoring methods rely heavily on manual sampling and laboratory testing, which are time consuming, labour-intensive, and often fail to provide real-time results.

With advancements in the Internet of Things (IoT) and Artificial Intelligence (AI), it has become possible to develop automated and intelligent monitoring systems that provide continuous, real-time insights into environmental conditions. IoT enables seamless data collection through interconnected sensors, while AI facilitates data analysis, pattern recognition, and predictive decision-making. In this context, this project proposes an IoT-enabled and AI-driven water quality monitoring and control system for aquaculture environments. The system is designed to continuously monitor critical water parameters using sensors connected to Arduino Uno and ESP32, transmit data to a cloud platform, and apply AI techniques to detect anomalies and generate alerts. This approach enhances efficiency, reduces manual intervention, and supports sustainable aquaculture practices.

Aquaculture plays a crucial role in global food security and environmental sustainability, where maintaining optimal water quality is essential for the healthy growth of aquatic organisms. Traditional monitoring methods are often time-consuming, labor-intensive, and less effective for real-time decision-making. To address these limitations, this work presents an IoT and AI-based water quality monitoring and control system that enables continuous, automated supervision of aquaculture environments. The system integrates multiple sensors to measure key water parameters such as pH, temperature, turbidity, total dissolved solids (TDS), and ammonia levels. These readings are processed using microcontrollers and transmitted to a cloud platform for real-time monitoring and analysis. An artificial intelligence model is employed to detect anomalies, predict potential risks, and classify water quality conditions for timely intervention. This approach enhances monitoring accuracy, reduces manual effort, and supports sustainable and efficient aquaculture management.

This system combines embedded technology, machine learning, and wireless communication to create a smart and efficient water monitoring solution suitable for modern environmental challenges.

II. METHODOLOGY

The proposed IoT-enabled and AI-driven water quality monitoring system for aquaculture is designed to continuously observe, analyse, and control critical water parameters in real time. The system integrates hardware sensors, microcontrollers, cloud computing, and artificial intelligence to ensure efficient and automated monitoring.

Initially, water quality parameters such as temperature, pH, turbidity, total dissolved solids (TDS), and ammonia levels are measured using dedicated sensors placed in the aquaculture environment. These sensors are interfaced with an Arduino Uno and ESP32 microcontroller, which act as the central data acquisition and communication units. The collected data is processed and transmitted wirelessly to a cloud platform via Wi-Fi using ESP32. An AI model is applied to analyze historical and real-time data to detect anomalies, identify trends, and predict potential water quality issues. Based on predefined threshold values and AI predictions, the system generates alerts and updates status indicators such as safe, warning, and critical conditions.

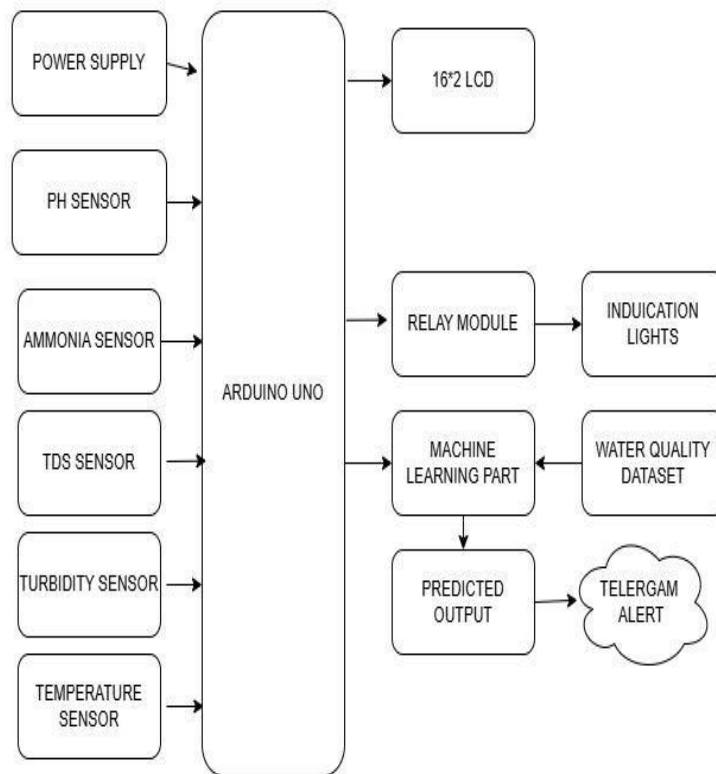


Fig.1.Block diagram

Based on the analysis, the system categorizes water quality into different levels such as safe, warning, and critical. When abnormal conditions are detected, alerts are generated and sent to the user through a Telegram notification. Next, the data is transmitted to a cloud or storage system, where it is stored and organized as a dataset. This dataset is used by the machine learning module to train and analyze water quality patterns. The AI model is designed to detect anomalies, classify water conditions, and predict potential issues based on historical and real-time data.

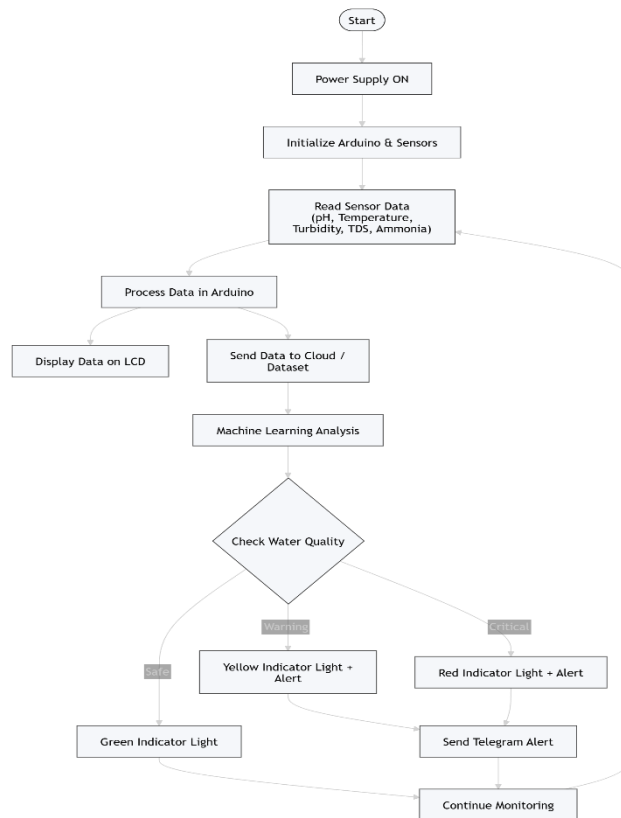


Fig 2.Flow chart

Additionally, a relay module is used to control external devices like pumps or aerators, and indication lights provide a visual representation of water quality status. Overall, this methodology ensures continuous monitoring, intelligent analysis, timely alerts, and automated control for efficient aquaculture management.

Finally, users can access the system remotely through a dashboard, allowing them to monitor aquaculture conditions in real time from any location. This enables timely decision-making by providing up-to-date insights on water quality, feeding schedules, and fish health indicators. As a result, farmers can respond quickly to potential issues, improving overall fish productivity and ensuring efficient more sustainable aquaculture management.

Overall, the proposed methodology integrates IoT and artificial intelligence to enable continuous and automated water quality monitoring in aquaculture systems. Sensor nodes measure key parameters such as pH, temperature, turbidity, TDS, and ammonia, which are processed by an Arduino-based controller and transmitted to a cloud platform for storage and analysis. A machine learning model evaluates the incoming data to detect anomalies, predict potential water quality issues, and classify conditions into safe, warning, or critical levels. Based on this classification, the system triggers visual indicators and sends real-time alerts through Telegram for immediate action when necessary. The entire process operates in a continuous loop, ensuring real-time monitoring, early detection of risks, and timely intervention, thereby improving efficiency and supporting sustainable aquaculture management.

III. CIRCUIT IMPLEMENTATION

The IoT and AI-based water quality monitoring system for aquaculture is designed around the Arduino Uno, which serves as the central processing unit. It collects input data from multiple water quality sensors, processes the signals, and coordinates communication with output devices and IoT modules.

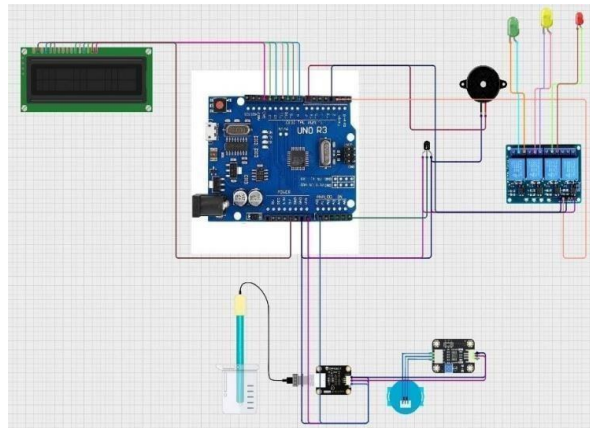


Fig.3.Circuit diagram of water quality monitoring and controlling system using IoT

The control and actuation part of the circuit is managed by a 4-channel relay module, which provides the necessary electrical isolation between the low-voltage DC electronics and the high-voltage AC indicators. Each relay channel is wired to one of three different colored light bulbs (red, blue, and white/yellow) that represent various water quality states. Additionally, the circuit diagram shows a piezo buzzer integrated into the digital output pins to provide an audible alarm when critical levels are detected. The entire setup is powered through the Arduino's USB interface or external power jack, ensuring a regulated 5V DC supply for the sensors and logic components, while the relays safely switch the external mains power to the status bulbs based on the programmed logic.



Fig.4.Arduino Uno Board

This is the core control unit (MCU) that coordinates all system activities. It receives data from multiple sensors, processes the values based on programmed logic, and triggers the appropriate output devices like the LCD and relays.



Fig.5.Temperature sensor

A digital probe used to measure the water temperature accurately. This data is crucial because water quality parameters like pH and oxygen solubility are temperature-dependent. The system utilizes the DS18B20 temperature sensor, which is a waterproof digital probe designed to measure the thermal state of the water. Unlike analog sensors, this digital sensor provides precise readings that are less susceptible to signal noise over long distances. In this architecture, the sensor serves as a primary input to the Arduino Uno microcontroller, allowing the system to track fluctuations in water temperature in real-time.



Fig.6.Turbidity sensor

The turbidity sensor is a critical component used to measure the physical clarity of the water by detecting the presence of suspended particles. It operates on the principle of light scattering, where an infrared light source is emitted into the water and a receiver measures the amount of light that is reflected or blocked by impurities such as silt, clay, or organic matter. The sensor outputs an analog voltage signal that is interpreted by the Arduino Uno microcontroller, which then converts this signal into Nephelometric Turbidity Units



Fig.7.pH sensor

The pH sensor detects the concentration of hydrogen ions in the water, providing a numeric value on a scale from 0 to 14. This measurement is vital because extreme pH levels can indicate chemical pollution, affect the solubility of nutrients and heavy metals, and impact the health of aquatic life. In your specific system, the pH data is used to trigger different status lights via the relay module—such as a Red light for hazardous pH levels or a White light for neutral, safe water.



Fig.8.16x2 LCD display

This liquid crystal display provides a real-time visual interface. It shows the exact numerical values of the water parameters (pH, Temperature, etc.) directly to a user standing near the device.

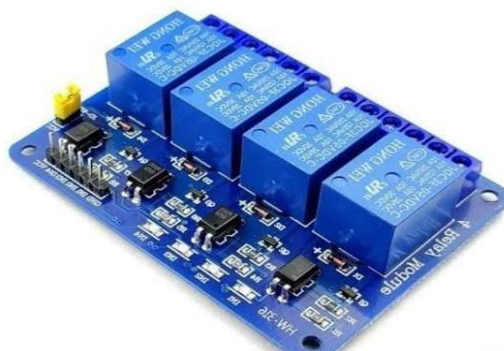


Fig.9.Relay module

This acts as an electromagnetic switch that allows the 5V Arduino to control high-voltage AC devices. Each channel can independently turn on or off a specific indicator light or external pump.

Power Supply: This module regulates and provides the steady electrical energy required for the Arduino and sensors to function reliably.

IV. RESULTS

In this paper, The IoT-enabled aquaculture monitoring system successfully tracked key water quality parameters, including pH, temperature, turbidity, TDS, and ammonia, in real time with consistent accuracy. The system demonstrated reliable continuous monitoring, ensuring timely detection of environmental changes that could affect fish health. By automating data collection and analysis, the proposed solution significantly reduced manual intervention and minimized human errors. Overall, the system improved operational efficiency, enhanced fish survival rates, and increased productivity in aquaculture management. In addition, the platform proved to be scalable and cost-effective, making it suitable for sustainable and intelligent aquaculture practices.



Fig.10. Normal condition In the above figure, the green bulb is glowing that indicates the water quality is normal. The sensors have detected that water quality parameters like pH, temperature, TDS, NH₃ and turbidity are within the optimal range. Then the system gives the visual result in LCD display as normal.



Fig.11. Moderate condition

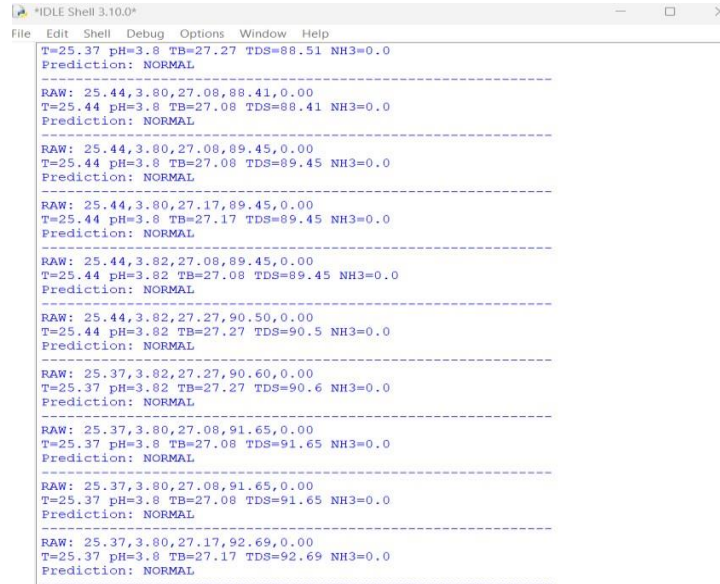
In the above figure, the glowing of blue bulb indicates the quality of the water is moderate and also sends an alert message to the user. That means the water is slightly outside the ideal range but not yet dangerous.



Fig.12. Critical condition

In the above figure the glowing of red bulb indicates the water quality is critical. The water has reached a threshold that is considered hazardous and also sends an alert message to the user.

Depending on the optimal range of water and the current condition of water the system lights up a specific LED bulb and sends alert messages to the user if the water is moderate or critical. So, that this system is used to reduce fish mortality and increase fish productivity.



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*IDLE Shell 3.10.0*
File Edit Shell Debug Options Window Help
T=25.37 pH=3.8 TB=27.27 TDS=88.51 NH3=0.0
Prediction: NORMAL
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RAW: 25.44,3.80,27.08,88.41,0.00
T=25.44 pH=3.8 TB=27.08 TDS=88.41 NH3=0.0
Prediction: NORMAL
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T=25.44 pH=3.8 TB=27.08 TDS=89.45 NH3=0.0
Prediction: NORMAL
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Prediction: NORMAL
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Prediction: NORMAL
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Prediction: NORMAL
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Prediction: NORMAL
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RAW: 25.37,3.80,27.08,91.65,0.00
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Prediction: NORMAL
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RAW: 25.37,3.80,27.08,91.65,0.00
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Prediction: NORMAL
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RAW: 25.37,3.80,27.17,92.69,0.00
T=25.37 pH=3.8 TB=27.17 TDS=92.69 NH3=0.0
Prediction: NORMAL
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Fig.13. Results obtained by the Algorithms

The integration of an AI-based model enables intelligent evaluation of water quality by detecting anomalies, identifying trends, and predicting potential risks. Based on the analysis, the system accurately classifies water conditions into safe, warning, and critical levels, ensuring timely decision-making. Immediate alerts through visual indicators and Telegram notifications enhance responsiveness during abnormal situations.



Fig.14. Alert message is received when the water is in moderate condition

V. CONCLUSION

The IoT-enabled aquaculture monitoring system provides an efficient and reliable solution for maintaining optimal water quality conditions in aquaculture environments. By integrating sensors, cloud computing, and AI-based analytics, the system enables real-time monitoring, data processing, and early detection of potential water quality issues. The automated alert mechanism supports timely corrective actions, thereby reducing risks and preventing fish mortality. Furthermore, the system minimizes manual intervention while significantly improving productivity and operational efficiency. In conclusion, the proposed solution offers a smart, scalable, and sustainable approach for modern aquaculture management, contributing to enhanced resource utilization and long-term environmental sustainability.

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