

DESIGN AND IMPLEMENTATION OF TINY ML - BASED WATER QUALITY MONITORING SYSTEM USING ESP32

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ABSTRACT

The Tiny ML-Based Water Quality Monitoring System on ESP32 is designed to monitor and evaluate water quality using pH, Total Dissolved Solids (TDS), and temperature sensors. The ESP32 acts as the main processing unit and collects sensor data continuously. The pH sensor measures the acidity or alkalinity of water, the TDS sensor measures the concentration of dissolved substances, and the temperature sensor measures water temperature. The collected sensor values are processed by a Tiny ML model deployed on the ESP32 to identify water-quality conditions and classify the water into suitable quality categories. Unlike conventional monitoring systems that mainly display individual sensor readings, the proposed system combines multiple parameters and uses machine learning for intelligent assessment. The system can provide real-time water-quality information and can be extended with IoT connectivity for remote monitoring. This approach provides a compact, low-cost, and intelligent solution for applications such as drinking-water monitoring, agriculture, aquaculture, and industrial water management.

Keywords: Tiny ML, ESP32, Water Quality Monitoring, Internet of Things (IoT), Edge Computing, Machine Learning, pH Sensor, TDS Sensor, Real-Time Monitoring.

II.LITERATURE REVIEW

Shruthi G.R. et al. (2024) [8] presented a comprehensive literature review and system

design monitoring temperature, pH, turbidity, and water ow. They emphasized maintaining pH within the ideal drinking water range of

6.5 to 8.5. Their implementation used Zigbee protocol for wireless data transmission between sensors and a central Raspberry Pi controller, highlighting the importance of communication protocols and sensor accuracy in active monitoring systems.

Kamarul Ha z Kamaludin et al. (2019) [9] proposed a smart water monitoring system using Node-RED and NodeMCU ESP32, showcasing web-based visualization platforms for environmental monitoring.

Their system included DS18B20 temperature and pH4502C sensors with calibration results showing voltage-to pH correlations (0.97V yielded pH 4.11; 2.40V yielded pH 10.25). Temperature sensor validation showed minimal error (0.01 to 1.92°C), corning data reliability. The Node-RED interface provided a user-friendly, responsive dashboard for real-time analysis.

Manisha Nimawat et al. (2022) [10] presented a low-cost Arduino UNO-based system monitoring pH, conductivity, turbidity, and temperature. Their modular design, powered by 5V supply with Wi-Fi transmission, emphasized accessibility and customizability for households, agriculture, and industry. This research contributed to the growing trend of DIY-style monitoring kits that are easy to install and maintain.

Wong Jun Hong et al. (2021) [11] developed a prototype using Arduino UNO R3 with pH, DS18B20 temperature, and turbidity sensors. The pH sensor operated actively within 10°C to 50°C, while the DS18B20 had a broader range (-55°C to 125°C) with 0.5°C accuracy. Programming in Arduino IDE (C/C++) supported easy customization and expansion, laying groundwork for future IoT-based monitoring developments.

III. EXISTING SYSTEM

In conventional water-quality monitoring systems, parameters such as pH, TDS, and temperature are measured using individual sensors and the readings are displayed on an LCD, serial monitor, or other monitoring device. The water quality is generally evaluated by comparing the measured values with predefined acceptable ranges.

Laboratory-based water testing methods can provide accurate results, but they require samples to be collected and analyzed using specialized equipment. Basic embedded monitoring systems provide faster measurements but generally depend on fixed threshold values and do not use machine-learning techniques to identify complex relationships between different water-quality parameters.

EXISTING SYSTEM DRAWBACKS

- Mainly depends on predefined threshold values.
- Limited intelligent analysis of sensor data.
- Individual sensor readings may not provide an overall water-quality assessment.
- Does not effectively identify complex relationships between pH, TDS, and temperature.
- Laboratory equipment can be expensive.
- Manual sample collection may be required.
- Conventional systems may have limited remote-monitoring capability.

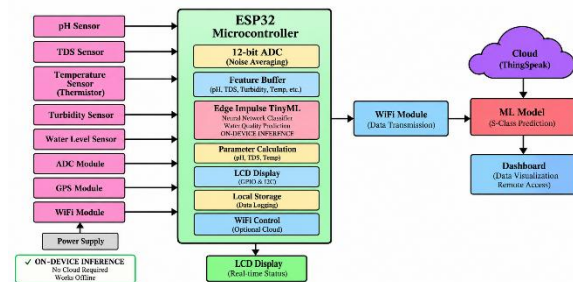
IV. PROPOSED SYSTEM

The proposed system uses an ESP32, along with pH, TDS, and temperature sensors, to develop an intelligent water-quality monitoring system. The sensors continuously measure the important water parameters and send the data to the ESP32.

The collected sensor data is processed by a Tiny ML model running directly on the ESP32. The model is trained using water-quality data containing combinations of pH, TDS, and temperature values. After deployment, the model analyzes new sensor readings and classifies the water condition according to the trained model.

The ESP32 performs the data processing locally, reducing the need to continuously send raw sensor data to an external server. The system can display the measured parameters and the predicted water-quality condition. IoT connectivity can also be added to transmit the results to a cloud platform or mobile application for remote monitoring.

V. BLOCK DIAGRAM



TDS SENSOR MODULE



The TDS (Total Dissolved Solids) sensor module measures the concentration of dissolved solids in water, expressed in parts per million (ppm). Total dissolved solids include minerals, salts, metals, and other inorganic compounds dissolved in the water. High TDS levels can

indicate water contamination and make water unsuitable for drinking. The TDS sensor operates on the principle of electrical conductivity water with a higher concentration of dissolved solids conducts electricity more efficiently, resulting in a higher measured conductivity value.

PH SENSOR MODULE



The pH sensor module used in this project consists of a pH electrode probe connected to an analog signal conditioning board. The pH electrode produces a small millivolt-level signal proportional to the hydrogen ion concentration of the water sample, which corresponds to the pH level. The signal conditioning board amplifies and converts this signal into a measurable analog voltage in the range of 0 to 3.3V, which is then read by the ESP32's ADC pin.

The pH measurement range of the sensor covers 0 to 14 pH units, which encompasses the full range from highly acidic to highly alkaline water conditions. The module

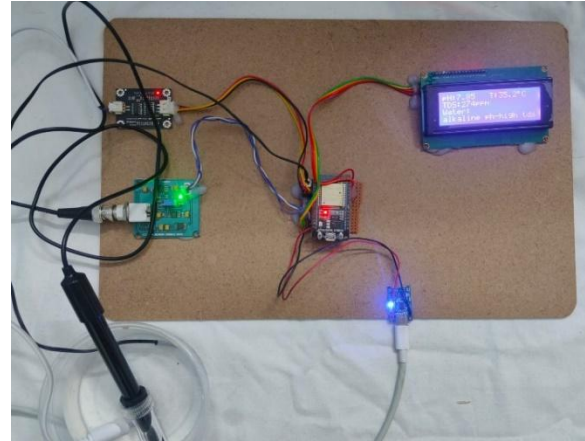
includes a BNC connector for attaching the pH probe and a potentiometer for calibration adjustment. The analog voltage output of the sensor varies inversely with pH — a higher voltage corresponds to a lower pH (acidic) and a lower voltage corresponds to a higher pH (alkaline). In this project, the raw analog voltage value from the pH sensor is used directly as one of the input features for the TinyML classification model, rather than converting it to a calibrated pH value, which simplifies the signal processing pipeline.

TEMPERATURE SENSOR (THERMISTOR)



An NTC thermistor is a type of resistor whose electrical resistance decreases as temperature increases. When connected in a voltage divider configuration with a fixed reference resistor, the thermistor produces a variable analog voltage output that changes proportionally with the temperature of the surrounding medium, in this case the water being tested.

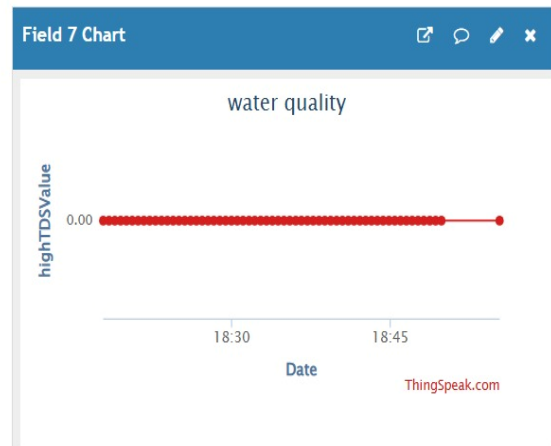
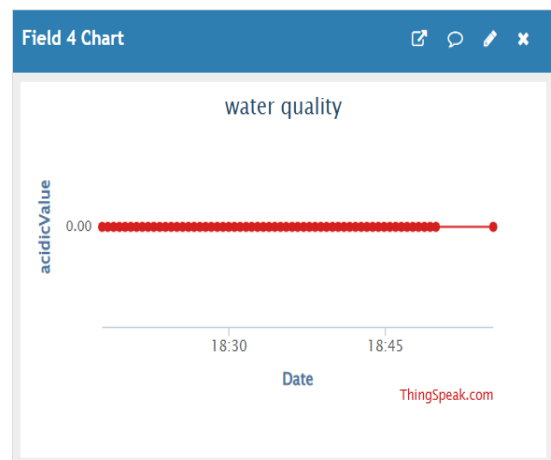
The analog voltage output from the thermistor module is read by the ESP32's ADC and used as the third input feature for the Tiny ML classification model. Water temperature is an important parameter in water quality assessment because it affects the solubility of gases and salts, the rate of chemical reactions, and the overall chemical equilibrium of the water

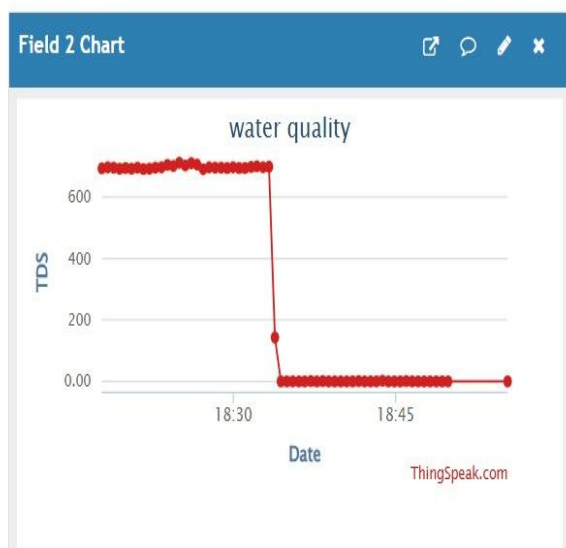


VI.RESULTS

The developed system continuously measures pH, TDS, and water temperature and processes the collected values using the Tiny ML model deployed on the ESP32. The system provides real-time sensor readings and generates a water-quality classification based on the trained model.

The prototype demonstrates that Tiny ML can be implemented on a resource-constrained ESP32 for local water-quality analysis. The system can provide faster monitoring and reduce dependence on manual interpretation of individual sensor readings. The performance of the final classification depends on the quality, quantity, and diversity of the training dataset used for the Tiny ML model.





VII.ADVANTAGES

- Real-time water-quality monitoring.
- Uses pH, TDS, and temperature parameters together.
- Provides intelligent water-quality classification.
- Reduces dependence on fixed threshold-based analysis.
- Compact and low-cost system.
- Low power consumption compared with many cloud-dependent approaches.

VIII.APPLICATIONS

- Drinking-water quality monitoring.
- Household water-quality monitoring.
- Agriculture and irrigation-water monitoring.

- Aquaculture and fish-farming systems.
- Industrial wastewater monitoring.
- Lakes, ponds, and reservoirs.
- Remote water-quality monitoring systems.

IX.CONCLUSION

The Design and Implementation of Tiny ML-Based Water Quality Monitoring System on ESP32 provides an intelligent and compact approach to monitoring water quality. By combining pH, TDS, and temperature sensors with an ESP32 and Tiny ML model, the system can collect multiple water-quality parameters and perform local intelligent classification. The proposed system reduces the limitations of conventional threshold-based monitoring and provides a foundation for real-time and IoT-enabled water-quality analysis. With suitable calibration and a representative training dataset, the system can be adapted for different water-monitoring applications.

X. FUTURE SCOPE

The system can be further enhanced by incorporating additional water-quality sensors such as turbidity, dissolved oxygen, conductivity, and oxidation-reduction potential sensors to improve the accuracy of

water-quality assessment. A larger and more diverse dataset can be used to train the Tiny ML model so that it can recognize a wider range of water-quality conditions. The ESP32 can also be connected to a cloud platform or mobile application for remote monitoring, historical data analysis, and alerts. Future versions can include predictive models capable of identifying potential water-quality deterioration before it reaches critical levels. The system can also be developed with solar power and low-power communication technologies for long-term deployment in remote water-monitoring locations.

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