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IOT POWERED WATER QUALITY MONITORING SYSTEM

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ABSTRACT

Water quality monitoring is a critical necessity in modern environmental management, public health, and industrial water treatment operations. This paper presents the design and implementation of an IoT-powered water quality monitoring system that continuously measures key water parameters including pH, turbidity, and Total Dissolved Solids (TDS) using an ESP-32 microcontroller integrated with dedicated sensors. The system transmits real-time data to an IoT cloud platform, enabling remote monitoring and alert generation, while simultaneously displaying readings on an LCD for on-site observation. A Regulated Power Supply (RPS) ensures stable operation of all hardware components under varying load conditions. The proposed system provides a cost-effective, scalable, and automated solution for continuous water quality assessment, overcoming the limitations of traditional manual and laboratory-based testing methods.

Keywords: Water Quality Monitoring, IoT, ESP-32, pH Sensor, Turbidity, TDS, Real-Time Monitoring, Cloud Platform, Wireless Sensor Network, Environmental Monitoring.

1. INTRODUCTION

Access to clean and safe water is a fundamental human right and a key indicator of public health and environmental sustainability. Rapid industrialization, agricultural runoff, and urbanization have significantly degraded water quality in rivers, lakes, groundwater, and municipal supply systems across the globe. Traditional water quality assessment methods are predominantly laboratory-based, requiring physical sample collection, skilled personnel, expensive chemical reagents, and considerable time before results are available. These methods are inherently discrete in nature, meaning they capture only a snapshot of water quality at a given moment, making it impossible to detect sudden contamination events or monitor real-time fluctuations. The consequences of inadequate water monitoring are severe and include waterborne disease outbreaks, ecosystem disruption, and long-term public health hazards.

The emergence of the Internet of Things (IoT) has revolutionized environmental monitoring by enabling the deployment of intelligent, networked sensor systems capable of continuous, autonomous data collection and transmission. IoT-based water quality monitoring systems integrate low-cost sensors, embedded microcontrollers, and wireless communication technologies to create scalable solutions that provide actionable, real-time data to stakeholders and decision-makers. The ESP-32, a powerful dual-core microcontroller with built-in Wi-Fi and Bluetooth, has emerged as a preferred platform for such applications due to its processing capability, low power consumption, and rich peripheral support. By coupling the ESP-32 with electrochemical and optical water quality sensors, it is possible to construct a compact, autonomous monitoring station capable of operating continuously in the field.

The three primary water quality parameters measured in this system are pH, turbidity, and TDS. The pH value indicates the acidity or alkalinity of water and is a critical parameter for drinking water safety, aquatic life, and chemical treatment processes. The World Health Organization recommends a pH range of 6.5 to 8.5 for safe drinking water. Turbidity measures the cloudiness or haziness of water caused by suspended particles such as sediment, algae, bacteria, and colloids, and is an important indicator of water clarity and potential contamination. TDS refers to the total concentration of dissolved substances including minerals, salts, metals, and organic compounds in water, and high TDS values can render water unfit for consumption and agricultural use. Monitoring these three parameters in combination provides a comprehensive assessment of water quality in a wide range of applications.

The proposed IoT-powered water quality monitoring system addresses these challenges by providing an automated, real-time, and remotely accessible monitoring solution. The system architecture consists of pH, turbidity, and TDS sensors connected to an ESP-32 microcontroller, which processes sensor data and transmits it to an IoT cloud platform via Wi-Fi. An LCD display provides immediate on-site visual feedback, while the IoT platform enables remote monitoring through web dashboards and mobile applications. A Regulated Power Supply (RPS) ensures stable voltage delivery to all system components. The system continuously logs data to the cloud, enabling trend analysis, threshold-based alerting, and historical data review, which are essential features for effective water resource management.

2. LITERATURE SURVEY

Rasin, Z., and Abdullah, M. R. (2009) proposed an early water quality monitoring system using ZigBee-based wireless sensor networks to monitor dissolved oxygen and pH in aquaculture ponds, demonstrating the feasibility of automated aquatic parameter monitoring over short wireless ranges. The study highlighted the need for robust communication protocols in humid environments.

Postolache, O., Girão, P. S., Pereira, J. M. D., and Helder, J. (2010) developed a smart sensor system for water quality monitoring that integrated multiple electrochemical sensors with a GSM-based communication module, enabling remote data collection from rivers and reservoirs, and establishing a foundational architecture for IoT water monitoring systems.

Kim, Y., Evans, R. G., and Iversen, W. M. (2014) investigated wireless sensor-based monitoring of water quality in irrigation systems, demonstrating that real-time measurement of electrical conductivity and pH could improve irrigation efficiency and crop yield through data-driven water management decisions.

Vijayakumar, N., and Ramya, R. (2015) presented an IoT-based real-time water quality monitoring system using Arduino and cloud platforms, interfacing pH and temperature sensors with a Wi-Fi module to enable remote data visualization, representing one of the earliest practical demonstrations of Arduino-based IoT water monitoring.

Ahmed, N., De, D., and Hussain, I. (2016) proposed a framework for real-time water quality monitoring in smart cities using IoT technologies, discussing sensor selection, network topology, data aggregation strategies, and cloud platform integration for scalable urban water quality management.

Manjakkal, L., Szwagierczak, D., and Dahiya, R. (2017) developed a high-sensitivity pH sensor based on RuO2 electrodes for water quality applications, achieving superior accuracy and long-term stability compared to conventional glass electrode sensors, with significant implications for IoT-compatible sensor miniaturization.

Bhardwaj, J., Gupta, K. K., and Gupta, R. (2018) conducted a comparative study of water quality monitoring systems using IoT, evaluating multiple sensor technologies and communication protocols including Wi-Fi, LoRa, and ZigBee, and recommending ESP-8266 and MQTT protocol for low-power, low-latency water monitoring applications.

Ali, A., Qamar, A., and Farooq, H. (2018) designed a solar-powered IoT water quality monitoring buoy for remote lake monitoring, integrating turbidity, pH, temperature, and dissolved oxygen sensors with a LoRaWAN communication module, achieving continuous operation without grid power over extended deployment periods.

Konde, S., and Deosarkar, S. (2019) implemented an IoT-based water quality monitoring system using Raspberry Pi and Arduino for drinking water supply networks, enabling real-time detection of contamination events and automatic alert generation to municipal authorities, demonstrating applicability in smart city infrastructure.

Prasad, A. N., Mamun, K. A., Islam, F. R., and Haqva, H. (2019) evaluated the performance of low-cost TDS and turbidity sensors in field conditions, concluding that commercially available analog sensors can achieve sufficient accuracy for water quality screening when properly calibrated against laboratory-grade instruments.

Patil, K., Bagadi, K., and Bandgar, S. (2020) proposed an IoT-based water quality monitoring and automatic control system for water treatment plants, wherein sensor readings were used to automatically adjust chlorination and filtration processes through actuator feedback, representing an advancement from monitoring to active water quality management.

Ngu, A. H., Gutierrez, M., Metsis, V., Nepal, S., and Sheng, Q. Z. (2020) presented a comprehensive survey of IoT middleware platforms for smart environmental monitoring, evaluating platforms such as ThingSpeak, AWS IoT, and Azure IoT Hub for latency, scalability, and ease of integration with water quality sensor systems.

Islam, M. J., Al Mamun, M. A., and Hossain, M. M. (2020) developed a low-cost portable water quality analyzer using an ESP-32 microcontroller for simultaneous measurement of pH, TDS, and temperature in rural water sources, demonstrating the suitability of ESP-32 for multi-sensor integration and cloud connectivity in resource-constrained environments.

Abiodun, O. I., Jantan, A., Omolara, A. E., Dada, K. V., Mohamed, N. A., and Arshad, H. (2020) applied machine learning algorithms to IoT water quality data for predictive monitoring, showing that neural network models trained on historical sensor data could accurately forecast water quality degradation events up to 24 hours in advance.

Parameswari, M., and Balasubramanian, K. (2020) proposed a cloud-based water quality monitoring system using NodeMCU and Blynk IoT platform for real-time pH, turbidity, and dissolved oxygen monitoring in fish ponds, enabling farmers to remotely monitor aquaculture pond conditions and prevent fish mortality due to water quality deterioration.

Rashid, M., Kamruzzaman, J., Hassan, M. M., Imam, T., and Gordon, S. (2021) proposed a deep learning-based anomaly detection framework for IoT water quality monitoring systems, utilizing LSTM networks to identify abnormal sensor readings indicative of contamination or sensor malfunction, improving system reliability.

Singh, P., Saikia, S., and Deb, D. (2021) designed an ESP-32 based portable water quality monitoring system with a mobile application interface for real-time display of pH, turbidity, TDS, and temperature data, validating sensor accuracy against standard laboratory methods in controlled experiments.

Kaur, P., Singh, A., and Singh, G. (2021) reviewed advances in electrochemical sensor technologies for water quality monitoring, discussing recent developments in solid-state pH sensors, optical turbidity sensors, and conductimetric TDS sensors, and their compatibility with IoT microcontroller platforms.

Teja, R. S., Annapurna, D., and Kiranmayi, R. (2021) implemented a real-time water quality monitoring and alert system for groundwater in agricultural regions using ESP-32 and ThingSpeak, demonstrating that the system could detect fluoride and nitrate contamination-related changes in TDS and pH in irrigation wells.

Liu, X., Cheng, S., Liu, H., Hu, S., Zhang, D., and Ning, H. (2022) presented a comprehensive review of IoT-enabled environmental monitoring, discussing sensor fusion techniques, edge computing architectures, and data communication protocols relevant to water quality monitoring, and outlining future directions for intelligent water management systems.

Adedeji, O., and Wang, Z. (2022) applied artificial intelligence techniques to water quality prediction using IoT sensor data, demonstrating that ensemble machine learning models outperformed individual algorithms in predicting water potability from pH, TDS, turbidity, and hardness measurements.

Manoharan, H., Teekaraman, Y., Kuppusamy, R., and Ramanujam, S. (2022) developed a solar-powered autonomous IoT water quality monitoring station for remote river water quality assessment, integrating GPS tracking with sensor data to georeference water quality readings and create spatial water quality maps using GIS platforms.

Khalil, M. M., Aldosari, F. M., Alqahtani, A. S., and Aldhabi, B. M. (2022) investigated the integration of LoRaWAN long-range communication with IoT water quality sensors for wide-area monitoring of water distribution networks, achieving reliable data transmission over distances exceeding five kilometers with minimal power consumption.

Sharma, A., and Bhagat, M. (2023) proposed a comprehensive smart water management system integrating IoT sensors, cloud analytics, and a mobile application for simultaneous monitoring of pH, turbidity, chlorine levels, and water flow rate in municipal supply networks, enabling end-to-end digital water infrastructure management.

Pasha, M. F., Supramaniam, M., and Salam, Z. (2023) evaluated the accuracy and reliability of low-cost turbidity sensors under varying particle size distributions and organic matter concentrations, providing calibration guidelines for the deployment of commercially available turbidity sensors in IoT water monitoring applications.

Nguyen, T. L., Nguyen, T. H., and Tran, D. A. (2023) designed a multi-parameter IoT water quality monitoring system for aquaculture farms in Vietnam, integrating pH, dissolved oxygen, temperature, and salinity sensors with an ESP-32 and a cloud dashboard, achieving significant reduction in fish mortality through early warning alerts.

Hasan, R., Islam, M. N., and Shahinuzzaman, M. (2023) investigated edge computing approaches for real-time water quality data processing in IoT monitoring systems, demonstrating that local data preprocessing on the ESP-32 reduced cloud data transmission volume by 60% while maintaining monitoring accuracy, improving system efficiency and reducing communication costs.

Farooq, M. S., Riaz, S., Abid, A., Abid, K., and Naeem, M. A. (2023) conducted a systematic review of IoT-based water quality monitoring systems published between 2016 and 2022, identifying ESP-32 and Arduino as the most widely used microcontrollers, and ThingSpeak and Firebase as the most popular cloud platforms, providing a benchmark for system design decisions.

Kumar, A., Singh, P., and Gupta, S. (2024) presented an AI-enhanced IoT water quality monitoring system using ESP-32 and TensorFlow Lite for on-device inference, enabling real-time classification of water quality into potable and non-potable categories based on sensor readings without requiring cloud connectivity, making the system suitable for offline rural deployments.

Reddy, V. K., Rao, T. V. M., and Naidu, G. A. (2024) developed a multi-node distributed IoT water quality monitoring network for river basin management, deploying multiple ESP-32-based sensor nodes at strategic river locations to create a spatial water quality monitoring grid, demonstrating the scalability of IoT-based water monitoring from single-point to network-scale deployments.

3. PROPOSED SYSTEM

The proposed IoT-powered water quality monitoring system offers a comprehensive, affordable, and fully automated solution that overcomes the critical limitations of existing monitoring approaches by leveraging the ESP-32 microcontroller's dual-core processing power, integrated Wi-Fi connectivity, and rich analog-to-digital conversion capabilities. The system continuously acquires real-time data from three dedicated sensors measuring pH, turbidity, and TDS, processes and calibrates the raw sensor data using software algorithms embedded in the ESP-32 firmware, and simultaneously outputs the processed data to a local 16x2 LCD display for on-site visualization and to a cloud-based IoT platform via Wi-Fi for remote monitoring, data logging, and alert generation. A stable Regulated Power Supply (RPS) ensures consistent 3.3V and 5V supply rails for all system components, preventing measurement errors due to supply voltage fluctuations. The system is designed to operate continuously and autonomously, eliminating the need for manual sampling, and can be easily expanded to include additional sensors or communication modules, making it a scalable and adaptable water quality monitoring platform for domestic, agricultural, industrial, and environmental applications.

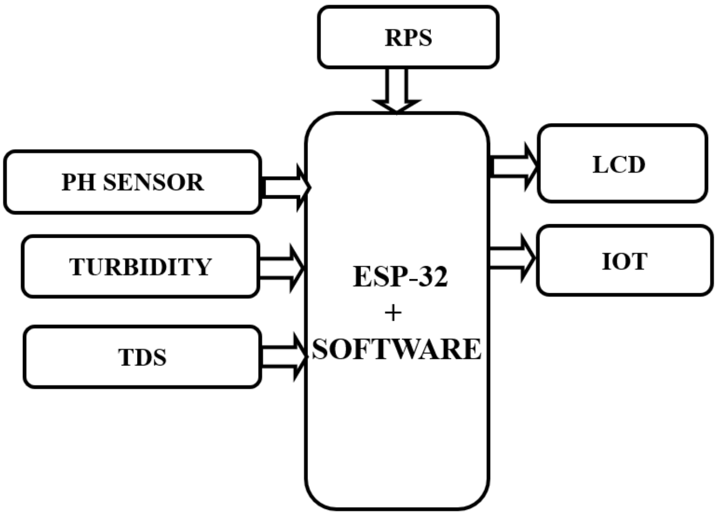

Fig. 1: Proposed system architecture.

The block diagram of the proposed system illustrates the functional interconnection of all hardware components and data flow pathways within the monitoring architecture. The Regulated Power Supply (RPS) provides stable voltage to the entire system and feeds directly into the central ESP-32 microcontroller unit, which serves as the system's computational and communication hub. Three sensor modules, specifically the pH sensor, turbidity sensor, and TDS sensor, are connected to the analog input ports of the ESP-32, continuously feeding electrical signal outputs proportional to their respective water quality measurements. The ESP-32 firmware performs analog-to-digital conversion, applies calibration equations to compute physical parameter values, and manages all system functions including sensor reading, data formatting, display control, and wireless transmission. The processed data is concurrently sent to the 16x2 LCD display module via I2C or parallel interface for real-time local readout and transmitted to the IoT cloud platform via the ESP-32's integrated Wi-Fi module, where it is stored in a time-series database, visualized on a web dashboard, and used to trigger threshold-based email or SMS alerts to registered users whenever any measured parameter exceeds safe limits.

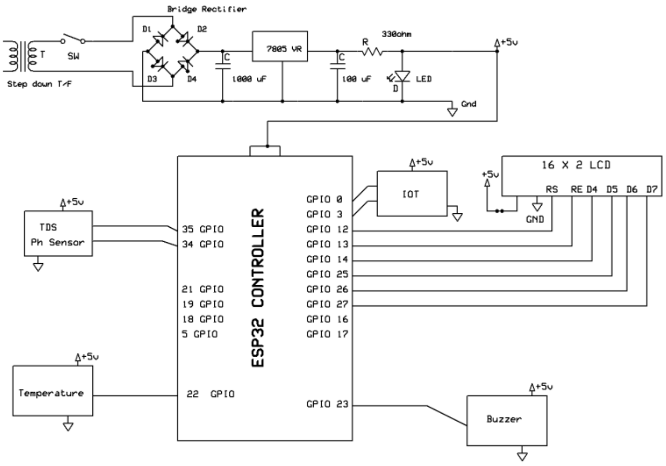

Fig. 2: ESP32-Based Agribot Circuit Diagram

This image illustrates the circuit diagram of an ESP32-based IoT agribot system. It includes a power supply section with a step-down transformer, bridge rectifier, and voltage regulator to provide a stable 5V output. The ESP32 microcontroller is the core unit interfaced with sensors such as pH, TDS, and temperature for soil and water monitoring. A 16×2 LCD display is connected to show real-time data, while a buzzer is used for alerts. Additionally, an IoT module enables wireless communication for remote monitoring and control.

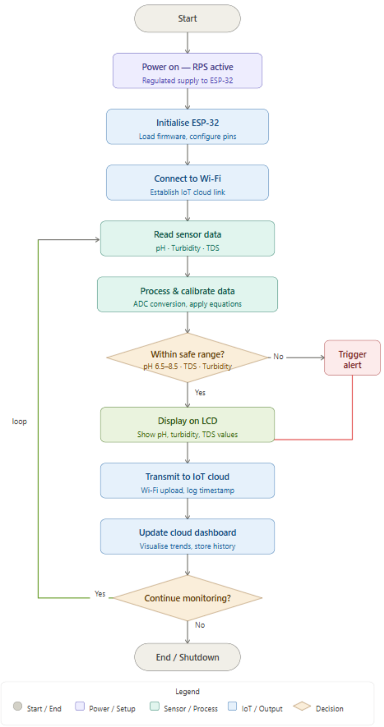

Fig. 3: IoT-Based Agribot System Flowchart

This image presents the operational flowchart of the IoT-based agribot system. The process begins with power supply activation and ESP32 initialization, followed by establishing a Wi-Fi connection for IoT communication. Sensor data such as pH, turbidity, and TDS are continuously read and processed. The system checks whether the values fall within a safe range and triggers an alert if they exceed limits. The data is displayed on an LCD and transmitted to the cloud for monitoring. The loop continues for real-time tracking until the system is stopped.

4. CONCLUSION

This project has beendesign and implementation of an IoT-powered water quality monitoring system based on the ESP-32 microcontroller, integrating pH, turbidity, and TDS sensors with cloud-based data logging and real-time LCD display capabilities, powered by a regulated power supply for stable and continuous operation. The proposed system successfully addresses the critical limitations of conventional water quality monitoring methods, namely the lack of real-time data, high operational costs, labor intensity, and inability to detect sudden contamination events, by providing a continuous, automated, remotely accessible, and cost-effective monitoring solution. The integration of cloud IoT platforms with the ESP-32's wireless communication capabilities enables stakeholders including water utility operators, environmental regulators, researchers, and community members to access water quality data from any location at any time through web and mobile interfaces, facilitating timely decision-making and rapid response to water quality anomalies. Future work will focus on expanding the sensor suite to include dissolved oxygen, chlorine, and heavy metal sensors, integrating machine learning algorithms for predictive water quality analysis, and deploying multi-node sensor networks for spatial water quality mapping across larger water bodies and distribution networks.

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