Aquatic Environment's Pollutant Detection Using Wsn Sensor Nodes Based Embedded System

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***Abstract*—This project presents a low-cost, real-time water quality monitoring system using Wireless Sensor Network (WSN) nodes based on the ESP32 microcontroller. Various sensors including pH, turbidity, temperature, and Total Dissolved Solids (TDS) are integrated to collect data from aquatic environments. The collected data is transmitted via Wi-Fi to the Blynk cloud platform for continuous remote monitoring. The system aims to assist in the detection of water pollution and aid environmental agencies and researchers in taking timely preventive measures.**

1. INTRODUCTION

Water pollution poses a serious threat to environmental and human health, especially when undetected in time. Traditional water quality monitoring methods are slow, labor-intensive, and not suitable for continuous assessment. This project proposes a smart, real-time solution using an IoT-based embedded system built around the ESP32 microcontroller. By integrating various sensors—such as pH, turbidity, temperature, and TDS—with wireless data transmission and cloud monitoring via Blynk, the system provides efficient, remote tracking of water quality. The goal is to ensure immediate detection of pollutants and support timely corrective actions for better aquatic ecosystem management

1.1 OBJECTIVE

The main objective to develop an embedded system capable of continuously measuring critical water parameters such as temperature, pH, turbidity, Total Dissolved Solids (TDS), and location (via GPS) in real-time. Utilize ESP32 microcontrollers and wireless communication protocols to transmit data from sensor nodes to a centralized cloud platform for monitoring, analysis, and visualization. Design an energy-efficient monitoring setup by integrating rechargeable lithium-ion batteries and optimizing sensor data acquisition cycles to extend operational life in remote locations. Display real-time sensor data locally on an LCD screen and remotely through a cloud-based dashboard, making data easily accessible for researchers, authorities, and water management teams.

1.2 MACHINE LEARNING

Machine learning (ML) can greatly enhance the functionality of the aquatic pollutant detection system by enabling intelligent analysis of water quality data. By using historical readings from sensors such as pH, turbidity, temperature, and TDS, ML algorithms can be trained to detect patterns and anomalies that indicate the presence of pollutants. These models can classify water quality conditions, identify specific types of contamination, and even predict future pollution events. Supervised learning methods like Random Forest or Support Vector Machines (SVM) can be used for classification tasks, while unsupervised techniques like clustering can uncover hidden trends in the environment. The integration of ML not only automates decision-making but also reduces the dependency on manual threshold-based systems, resulting in improved accuracy, faster response times, and the potential for scalable deployment in diverse aquatic ecosystems.

1.3 ADVANTAGES

Real-Time Monitoring: Continuously tracks water quality parameters, enabling immediate detection of contamination.

Remote Accessibility: Data is accessible from

anywhere using the Blynk cloud platform, improving responsiveness.
Low Power Consumption: Utilizes energy- efficient components and supports battery-powered operation for remote deployment.
Cost-Effective: Reduces the need for manual testing and lab analysis, lowering operational costs. Scalable and Portable: Compact design makes it easy to deploy in various environments including lakes, rivers, and reservoirs.
Multi-Parameter Detection: Measures a wide range of water quality indicators, offering comprehensive monitoring.
User-Friendly Interface: Real-time data is displayed on an LCD and a mobile app, making it easy for non-technical users to interpret.
GPS Integration: Allows precise location tracking of contamination sources for targeted interventions.
IoT-Enabled Alerts: Sends instant notifications when water quality exceeds safe thresholds.

2. LITERATURE REVIEW

1. Environmental Impacts and Challenges Associated with Oil Spills on Shorelines (2022)

Oil spills pose a significant threat to marine and coastal ecosystems, particularly along shorelines where the environmental impact is most concentrated and prolonged. This project investigates the environmental consequences of oil spills on shoreline habitats, including damage to flora and fauna, disruption of ecological balance, and contamination of soil and water resources. It also explores the challenges in oil spill detection, cleanup operations, and restoration efforts. Through case studies and scientific data, the project highlights the complexity of managing oil spill incidents and emphasizes the need for improved response strategies, preventive measures, and sustainable shoreline protection policies.

2. Oil spill trajectory modelling and environmental vulnerability mapping using GNOME model and GIS(2021)

This project focuses on predicting the movement and impact of marine oil spills through trajectory modeling and environmental vulnerability assessment. Using NOAA's General NOAA Operational Modeling Environment (GNOME) and Geographic Information System (GIS) tools, the study simulates oil spill trajectories based on ocean currents, wind data, and spill characteristics. It also maps environmentally sensitive areas to assess potential ecological damage. The integration of GNOME with GIS enhances the ability to plan timely response actions, prioritize at-risk habitats, and develop effective oil spill contingency strategies. The results support informed decision- making for coastal resource protection and emergency management

.3. Classification of oil spill by thicknesses using multiple remote sensors (2020)

Accurate classification of oil spill thickness is critical for effective environmental response and cleanup planning. This project focuses on utilizing multiple remote sensing technologies—such as optical, thermal, and radar sensors—to detect and classify oil spills based on their thickness. By integrating data from satellite and aerial imagery, the system distinguishes between thin sheens, rainbow layers, and thicker emulsions. Advanced image processing and data fusion techniques enhance classification accuracy. The project demonstrates how multi-sensor approaches can improve the monitoring of oil spill extent and severity, enabling faster decision-making and more targeted remediation strategies.

4. Wireless Sensor Networks for Detection and Localization of Subsea Oil Leakages (2021)

Subsea oil leakages present significant environmental and economic risks due to the difficulty in early detection and precise localization. This project explores the use of Wireless Sensor Networks (WSNs) deployed underwater to monitor and identify oil leaks in real time. The system involves a distributed network of sensor nodes equipped with hydrocarbon and pressure sensors, which communicate wirelessly to relay data to surface buoys or monitoring stations. Advanced algorithms are employed for leak localization based on signal strength, time delay, and sensor data correlation. The project highlights the potential of WSNs as a scalable, energy-efficient, and cost- effective solution for continuous underwater oil leakage monitoring.

3. EXISTING SYSTEM

Aquatic environment monitoring for pollutant detection primarily relies on traditional methods such as manual water sampling and laboratory testing. Researchers and environmental authorities collect water samples at various locations and transport them to laboratories for chemical analysis. Some modern systems employ remote sensing via satellites or basic automated sensor stations placed in fixed locations. These setups often measure parameters like pH level, turbidity, temperature, dissolved oxygen, and the presence of specific harmful chemicals. In a few advanced setups, wired sensor networks are installed to monitor water quality in real-time, but these systems are typically expensive, complex, and difficult to maintain, especially over large or remote water bodies.

4. PROPOSED SYSTEM

The proposed system is an IoT-based Aqua Monitoring System designed to continuously monitor water quality parameters using an embedded WSN (Wireless Sensor Network) approach. It addresses the limitations of traditional water quality monitoring methods by automating data collection, real-time transmission, and remote accessibility. A low-power microcontroller with built-in Wi-Fi and Bluetooth is used for data acquisition, processing, and wireless transmission. Sensor data is processed and transmitted to a cloud platform for real-time visualization, storage, and analysis. The system ensures that users receive immediate notifications if contamination or abnormalities in water parameters are detected. A rechargeable 12V cylindrical lithium-ion battery ensures uninterrupted power for field deployments. Real-time readings are shown on an LCD module for quick on-site assessment.

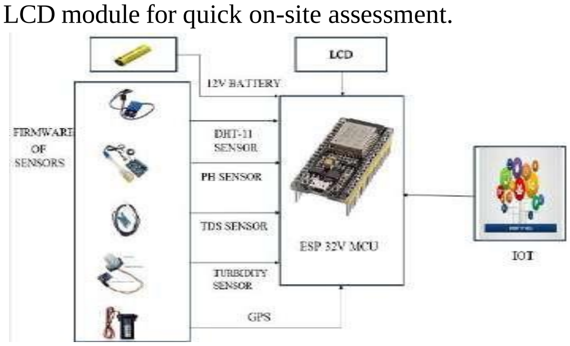


FIG 1. *PROPOSED BLOCK DIAGRAM*

5. SYSTEM REQUIREMENTS

5.1 Hardware Requirements

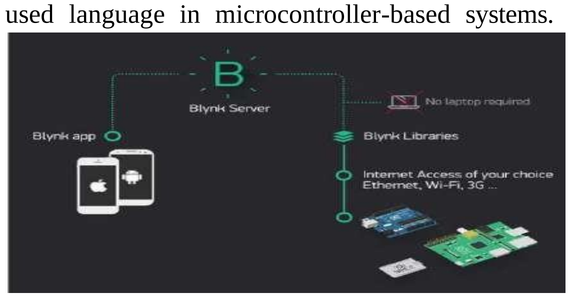
The proposed system utilizes the ESP32 microcontroller as the core processing unit due to its built-in Wi-Fi and Bluetooth capabilities, which support IoT connectivity. It includes various water quality sensors such as the pH sensor, turbidity sensor, TDS sensor, and DHT11 for temperature and humidity measurement. A GPS module is integrated for geolocation tracking of water bodies. To display real-time sensor data, a Liquid Crystal Display (LCD) is used. The entire system is powered by a rechargeable lithium-ion battery, chosen for its compact form factor and efficient power delivery. These components are selected to ensure the system is compact, portable, energy- efficient, and suitable for deployment in remote or aquatic environments.

5.2 Software Requirements

The software requirements for this aquatic pollutant detection system focus on efficient sensor data processing, communication, and remote monitoring. The primary development environment is the Arduino IDE, which is used to write and upload embedded C code to the ESP32 microcontroller. This code controls sensor operation, data acquisition, and transmission. The Blynk IoT platform is employed for cloud-based monitoring and alert generation, offering a mobile-friendly interface to display real-time water quality data. The AVR-GCC compiler is used to compile the embedded C programs. A Windows 11 PC serves as the development workstation for writing, debugging, and deploying code. Together, these tools ensure reliable data handling, user interaction, and system scalability.

5.3 Software Description

The core programming of the aquatic pollutant detection system is written in Embedded C, a widely used language in microcontroller-based systems.



Embedded C offers direct access to hardware-level operations, making it ideal for controlling the ESP32 microcontroller and interfacing with various sensors. It enables efficient management of sensor readings, decision-making logic, and data transmission processes. The structured and low- level nature of C ensures minimal memory usage and faster execution, which is crucial for real-time systems. In this project, C code is written and uploaded via the Arduino IDE, allowing the ESP32 to read sensor inputs, process them, display data on the LCD, and send it to the Blynk cloud platform for remote monitoring.

BLYNK IoT

Blynk is a platform that provides iOS and Android apps to control hardware like Arduino, Raspberry Pi, and similar devices over the Internet. It offers a digital dashboard where users can easily build graphic interfaces for their projects by dragging and dropping widgets. Setting up Blynk is extremely simple, allowing users to start creating projects within five minutes. Blynk is not restricted to any specific board or shield, making it highly versatile. It supports a wide range of hardware options, whether your Arduino or Raspberry Pi is connected via Wi-Fi, Ethernet, or the ESP8266 chip. Blynk enables you to get your hardware online and ready for the Internet of Things (IoT) environment with minimal effort.

BLYNK APPLICATION

Blynk is specifically designed for IoT applications. It allows users to control hardware remotely, display and store sensor data, visualize information, and perform many other advanced tasks. The Blynk platform is made up of three major components: the

Blynk App, the Blynk Server, and the Blynk Libraries. The Blynk App lets users create powerful and interactive interfaces for their projects by using a variety of widgets. The Blynk Server handles all communications between the smartphone and the connected hardware, and users can either connect through the public Blynk Cloud or set up a private server locally, even on simple devices like a Raspberry Pi. The server is open-source and capable of managing thousands of devices simultaneously.

The Blynk Libraries enable seamless communication between supported hardware platforms and the Blynk Server. They manage all incoming and outgoing commands efficiently. When a user presses a button in the Blynk App, the command travels to the Blynk Cloud, which quickly relays it to the connected hardware. The same mechanism works in reverse, providing real-time interaction that feels instantaneous, occurring in just a " blynk " of an eye.

THINKSPEAK

The core programming of the aquatic pollutant Thing Speak is an open-source IoT analytics platform that enables real-time data collection, storage, visualization, and analysis over the internet. In this project, Thing Speak can be used as an alternative or additional cloud platform to Blynk for monitoring water quality parameters. The ESP32 microcontroller transmits sensor data such as pH, turbidity, temperature, and TDS to Thing Speak using HTTP or MQTT protocols. This data is stored in dedicated channels and visualized through customizable graphs and dashboards. ThingSpeak also supports MATLAB analytics for real-time processing and predictive modeling, making it suitable for future machine learning applications. Its web-based interface allows users to monitor trends remotely and generate alerts when water quality exceeds predefined thresholds.

5.4 HARDWARE DESCRIPTIONS ESP32 CONTROLLER

The ESP32 is a series of low-cost, low-power system-on-a-chip microcontrollers with integrated Wi-Fi and dual-mode Bluetooth capabilities. The ESP32 series utilizes either a Tensilica Xtensa LX6 microprocessor, available in both dual-core and single-core variations, or a dual-core Xtensa LX7 microprocessor, or a single-core RISC-V microprocessor. It includes built-in antenna switches, an RF balun, a power amplifier, a low- noise receive amplifier, filters, and power management modules. Developed by Espressif Systems, a Shanghai-based company, and manufactured by TSMC using a 40 nm process, the ESP32 serves as the successor to the popular ESP8266 microcontroller.

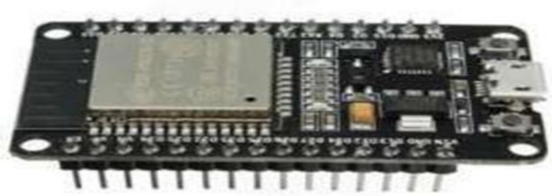


FIG 4: ESP32 CONTROLLER FEATURES

The ESP32 features a powerful processor setup with a 32-bit Xtensa dual-core (or single-core) LX6 microprocessor, operating at frequencies of 160 or 240 MHz and capable of delivering up to 600 DMIPS performance. It includes an Ultra Low Power (ULP) co-processor for energy-efficient operations. In terms of memory, the device offers 320 KiB of RAM and 448 KiB of ROM for program and data storage. The wireless connectivity of the ESP32 supports Wi-Fi standards 802.11 b/g/n and Bluetooth version 4.2, including BR/EDR and BLE, with the radio shared between Wi-Fi and Bluetooth functionalities.

In terms of security, the ESP32 supports all IEEE 802.11 standard security features, including WPA, WPA2, and WPA3 depending on the version. It also supports WLAN Authentication and Privacy Infrastructure (WAPI), secure boot, and flash encryption. The chip features a 1024-bit One Time Programmable (OTP) memory, with up to 768 bits available for customer applications. Cryptographic hardware acceleration is built-in for AES, SHA-2, RSA, elliptic curve cryptography (ECC), and a random number generator (RNG). Power management features are included with an internal low-dropout regulator, enhancing efficiency in various applications.

POWER SUPPLY

The power supply system is a crucial component of the aquatic pollutant detection system, as it ensures the continuous and reliable operation of all electronic modules, particularly in remote or inaccessible water bodies. This project utilizes a cylindrical lithium-ion battery as the primary power source, selected for its high energy density, rechargeability, compact design, and long cycle life. Lithium-ion batteries are widely used in embedded systems due to their ability to deliver consistent voltage and current, which is essential for the stable performance of microcontrollers and sensors.

The lithium-ion battery typically outputs a voltage in the range of 3.7V to 4.2V, which is regulated and distributed to power various components, including the ESP32 microcontroller, sensors (pH, TDS, turbidity, temperature, humidity), LCD display, and GPS module. A voltage regulator circuit or onboard regulator within the ESP32 is used to step down the battery voltage to a stable **3.3V**, which matches the operating requirement of most digital sensors and the microcontroller's logic levels.

LITHIUM-ION BATTERY

The aquatic pollutant detection system is powered by a rechargeable lithium-ion battery, which offers a compact, efficient, and reliable energy source suitable for embedded IoT applications. Lithium-ion batteries are preferred for their high energy density, long life cycle, and consistent voltage output, typically around 3.7V. In this project, the battery supplies power to the ESP32 microcontroller and various sensors, including pH, turbidity, TDS, temperature, and GPS modules. A built-in Battery

Management System (BMS) ensures safe operation by preventing overcharging, deep discharging, and short-circuiting. The battery is also compatible with solar charging circuits,
allowing future upgrades for sustainable operation. Its lightweight and rechargeable nature make it ideal for portable, field-deployable environmental monitoring systems, ensuring uninterrupted data collection even in remote or off-grid locations.

Battery → TP4056 → Boost Converter (if 5V needed) → AMS1117 → ESP32 + Sensors

pH SENSOR

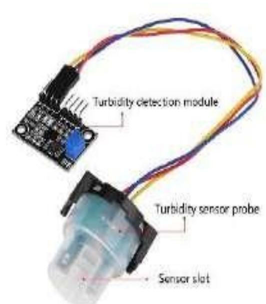
The pH sensor is used to measure the acidity or alkalinity of water by detecting hydrogen ion concentration. It consists of a glass electrode and a reference electrode that form
an electrochemical cell, producing voltage based on

pH levels. This analog signal is read by the ESP32's ADC. The sensor operates over a 0–14 pH range and 0°C–80°C temperature, making it suitable for environmental monitoring. It is calibrated using standard buffer solutions to maintain accuracy. pH readings help identify water contamination, ensure aquatic safety, and are crucial for real-time pollution detection in the proposed IoT-based monitoring system

TDS SENSOR

TDS meters work by measuring the electrical conductivity of water. It detects the Total Dissolved Solids (TDS) levels in the water which can be used to indicate the water quality. TDS sensors can measure a range of 0 to 1000 ppm or 0 to 5000 ppm. The required a DC voltage for working in the range of 3.3V to 5.5V.
The required temperature of working is 0°C to 50°C.

TURBIDITY SENSOR



It measures the overall clarity of water by looking at the amount of light scattered when it hits the surface of a water sample. If the light scattering is significant, this indicates that the water has high turbidity. Temperature range can be split into the operating temperature range and storage temperature range.
Measurement range is 0 – 400 NTU. Response time of the sensor quickly reacts to changes in turbidity.

DHT- 11 SENSOR

The DHT11 is a low-cost digital temperature and humidity sensor that uses a capacitive humidity sensor and a thermistor to measure surrounding air.
It provides digital output of both temperature and relative humidity via a single data pin. The sensor provides a digital signal on its data pin, eliminating the need for analog input pins on the microcontroller. It measures both temperature (0-50°C) and relative humidity (20-90% RH). The DHT11 can only send data once every 2 seconds.

GPS

The Global Positioning System (GPS) is a space-based radio navigation system that provides users with accurate information on position, velocity, and time. It utilizes a network of satellites to pinpoint the location of a mobile device, enabling navigation and other position-awareness applications. GPS receivers have varying levels of accuracy, ranging from consumer-grade devices with meters-level accuracy to high-end geodetic receivers with sub-centimeter accuracy. GPS receivers used outdoors often have water resistance ratings like IPX7. These systems provide differential corrections to enhance GPS accuracy.

6. RESULT ANALYSIS

7. CONCLUSION

The project successfully demonstrates a real-time, IoT-based solution for monitoring aquatic environmental pollution using WSN sensor nodes and an ESP32 microcontroller. By integrating various water quality sensors—such as pH, turbidity, temperature, and TDS—with wireless communication and the Blynk cloud platform, this system enables continuous, remote monitoring of water bodies. The implementation provides a cost-effective, scalable, and energy-efficient approach to water quality assessment, which is crucial for environmental protection, public health, and sustainable resource management. The system's modularity also allows for future enhancements such as automated alert systems, AI-based data analytics, and integration with government or research databases for broader environmental monitoring initiatives.

FUTURE ENHANCEMENT

To improve the performance and capabilities of the aquatic pollutant detection system, several future enhancements can be considered. One key advancement is the integration of machine learning algorithms to predict pollution trends based on historical sensor data, enabling proactive measures. Incorporating solar panels would ensure continuous power supply, making the system more sustainable and suitable for long-term remote deployments. The use of LoRa or NB-IoT communication modules can extend data transmission range, especially in areas lacking stable internet connectivity. Implementing automated contamination control, such as triggering water filtration or alerting nearby response units, can transform the system into a smart, closed-loop environmental management tool. Additionally, enhancing the data security through encryption methods will ensure safe data transmission and prevent manipulation. Expanding the system to support more chemical sensors, like dissolved oxygen or heavy metal detectors, will allow broader pollutant detection. A mobile app interface with GPS mapping and real- time alerts could improve user experience and accessibility. Overall, these improvements would make the system more intelligent, efficient, and applicable to diverse environmental needs.

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