



IoT-Enabled Smart Water Quality Monitoring System for Real-Time Measurement and Analysis

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Abstract: Water quality monitoring is essential for public health and environmental protection. Traditional methods, relying on periodic sampling and lab tests, are time-consuming, costly, and lack real-time data, making it difficult to quickly detect and address water quality issues. These systems also require manual intervention and are not scalable, especially in remote areas. Therefore, this project proposes an IoT-based smart system for real-time water quality monitoring and analysis using various sensors, such as TDS, turbidity, pH, temperature, ammonia, iron, carbonates, and others, to continuously monitor the water quality. These sensors send real-time data to the ESP-32 microcontroller, which processes the information and analyzes the water's current parameters. The system then displays the readings on a user interface, showing parameters like temperature, pH, dissolved oxygen, TDS, and more. If any parameter falls outside the acceptable range, an alarm is triggered, alerting users to potential issues, such as high temperature or imbalanced pH levels, as seen in the screenshot. In addition to current readings, the system also tracks the trends of parameters like TDS, ammonia, iron, and carbonates over time, helping users monitor fluctuations and detect patterns. The system offers an easy-to-understand graphical representation of these trends, allowing for quick detection of any abnormalities and providing the necessary insights for timely intervention.

Keywords: IoT, Water Quality Monitoring, TDS, Mineral Detection, ESP32, Smart System Analysis, Artificial Neural Network (ANN), Feature Selection

1. Introduction

Water is one of the most important natural resources for human survival and environmental sustainability. However, due to rapid industrialization, urbanization, and improper waste management, water sources are becoming increasingly polluted. Contaminated water can cause serious health problems and environmental

damage. Therefore, continuous monitoring of water quality has become essential.

Traditional water quality monitoring methods involve manual sample collection and laboratory testing. These methods are time-consuming, expensive, and do not provide real-time information. As a result, sudden changes in water

quality may not be detected immediately, which can lead to serious consequences.

With the advancement of the Internet of Things (IoT), it is now possible to monitor environmental parameters remotely and in real time. IoT technology allows sensors to collect data and transmit it to cloud platforms, where it can be analyzed and accessed from anywhere. This improves efficiency, reduces human effort, and enables faster decision-making.

In this project, an IoT-enabled smart water quality monitoring system is developed to measure important parameters such as pH, turbidity, and temperature. These sensors are connected to a microcontroller, which collects the data and sends it to an online platform through Wi-Fi. Users can monitor the water quality remotely in real time. The proposed system provides a reliable, low-cost, and efficient solution for water quality monitoring in domestic, industrial, and environmental applications.

2. Literature Review

Water quality monitoring is essential for maintaining safe water resources and protecting public health. With the advancement of Internet of Things (IoT) technology, several researchers have developed smart water quality monitoring systems to overcome the limitations of traditional manual methods.

Mukta et al. [1] developed an IoT-based smart water quality monitoring system that uses sensors to measure parameters such as pH, temperature, and turbidity. The collected data was transmitted to an online server, allowing users to monitor water quality remotely. Their system improved monitoring efficiency and reduced the need for manual intervention.

Fadel and Shujaa [2] proposed an IoT-based water quality monitoring system that integrates sensors with wireless communication technology. The system enabled real-time monitoring and data transmission to a cloud platform. Their

research demonstrated that IoT-based systems provide better accessibility and faster response compared to conventional monitoring methods.

Rao et al. [3] designed a real-time water quality monitoring system using the ESP32 microcontroller. The system collected sensor data and transmitted it through Wi-Fi to an online platform. The study showed that ESP32 is highly suitable for IoT applications due to its built-in Wi-Fi capability, fast processing speed, and low power consumption.

Geetha and Gouthami [4] developed an IoT-enabled water quality monitoring system that continuously monitored water parameters and sent the data to a remote server. Their system allowed real-time monitoring and helped detect water contamination at an early stage.

Singh et al. [5] proposed a smart water quality monitoring system using IoT and wireless sensor networks. Their system enabled continuous monitoring and improved reliability. The study highlighted the importance of IoT in improving water quality monitoring efficiency and reducing human effort.

Kumar and Hancke [6] presented an energy-efficient IoT-based environmental monitoring system. Their research focused on reducing power consumption while maintaining system performance. This approach is important for developing sustainable and long-term monitoring systems.

Although these existing systems provide real-time monitoring and improved efficiency, some systems still face challenges such as higher system cost, complexity, and limited scalability. Therefore, there is a need for a cost-effective, reliable, and efficient IoT-based water quality monitoring system. The proposed system uses the ESP32 microcontroller with integrated Wi-Fi capability to provide continuous monitoring, remote access, and improved performance.

3. Existing System

Existing water quality monitoring systems primarily rely on manual sampling and laboratory-based analysis. These methods have been widely used by municipal water authorities, environmental agencies, and industries to evaluate water safety and compliance with regulatory standards. Although these methods provide accurate and standardized results, they suffer from several operational and practical limitations.

The traditional monitoring process typically involves four major stages:

1. Sample collection
2. Sample preservation and transportation
3. Laboratory testing and analysis
4. Reporting and decision-making

Each stage contributes to delays and increased operational costs.

1. Sample Collection

In the conventional approach, water samples are collected manually from sources such as rivers, lakes, groundwater wells, reservoirs, or industrial discharge outlets. Trained personnel visit the site periodically (daily, weekly, or monthly) and collect samples in sterile containers.

2. Sample Preservation and Transportation

After collection, samples must be preserved using chemical reagents or refrigeration to prevent biological or chemical changes. The samples are then transported to a laboratory for testing.

3. Laboratory-Based Testing

Once the sample reaches the laboratory, various physical, chemical, and biological tests are conducted using specialized instruments.

3.1 Physical Parameters Testing

Physical characteristics such as turbidity, color, odor, and temperature are measured using instruments like turbidity meters and thermometers.

3.2 Chemical Analysis

Chemical parameters such as pH, Total Dissolved Solids (TDS), hardness, ammonia, iron, and carbonate concentration are analyzed using pH meters, Spectrophotometers, Titration methods, Conductivity meters.

Although laboratory instruments provide high precision, they require skilled technicians, Controlled laboratory environment, Expensive equipment, Regular calibration, Biological Testing, Microbiological contamination is tested using culture-based methods. Water samples are incubated to detect bacteria such as coliforms. But it requires incubation time (24–48 hours) and it cannot provide instant results, also it requires sterile laboratory conditions.

Existing water quality monitoring systems face the following challenges:

- Lack of real-time monitoring capability
- High operational and maintenance costs
- Manual sampling and delayed laboratory results
- Limited scalability in remote areas
- Inability to detect sudden contamination instantly

To overcome these limitations, a smart automated system capable of real-time monitoring and remote data visualization is required.

To improve efficiency, some existing systems have implemented embedded systems using microcontrollers such as Arduino for automatic data collection. These systems use sensors to measure water quality parameters and display the readings on local display units. However, these systems are limited in functionality because they do not provide remote monitoring capabilities. Users must be physically present at the monitoring location to observe the data.

In addition, certain systems use GSM-based communication to transmit water quality information via SMS. While this approach enables remote communication, it has several drawbacks, including higher operational cost,

limited data transmission speed, and lack of continuous monitoring. Furthermore, GSM-based systems do not provide efficient data storage and visualization for long-term analysis.

Most of the existing systems also lack integration with Internet of Things (IoT) technology, which is essential for real-time monitoring, cloud storage, and remote accessibility. These limitations highlight the need for a more efficient, low-cost and real-time water quality monitoring system. The proposed system addresses these challenges by using an ESP32 microcontroller with built-in Wi-Fi capability, enabling continuous monitoring and real-time data transmission to cloud platforms.

4. Proposed Methodology

The proposed system is designed to monitor water quality parameters in real time using an IoT-based approach. The system uses the ESP32 microcontroller as the main processing unit due to its built-in Wi-Fi capability, high performance, and low power consumption. The methodology involves sensing, processing, transmitting, and monitoring water quality data.

4.1 System Architecture

The proposed system consists of three main components: sensors, ESP32 microcontroller, and cloud platform. Water quality sensors such as pH sensor, turbidity sensor, and temperature sensor are used to measure important parameters of water. These sensors are connected to the ESP32 microcontroller, which collects and processes the sensor data.

The ESP32 transmits the collected data to a cloud platform through Wi-Fi. The cloud platform stores the data and displays it in graphical form, allowing users to monitor water quality remotely in real time.

4.2 Data Collection

The sensors continuously measure the physical and chemical properties of water.

- The pH sensor measures the acidity or alkalinity of water.
- The turbidity sensor measures the clarity of water by detecting suspended particles.
- The temperature sensor measures the temperature of water.

These sensors generate analog or digital signals based on the measured parameters. The ESP32 reads these signals through its input pins.

4.3 Data Processing

The ESP32 microcontroller processes the sensor data and converts it into meaningful values. The microcontroller uses programmed instructions to read sensor values at regular intervals. The collected data is calibrated and formatted for transmission.

The ESP32 ensures accurate and continuous monitoring of water quality parameters.

4.4 Data Transmission

After processing, the ESP32 sends the data to the cloud platform using its built-in Wi-Fi module. The Internet of Things (IoT) technology enables real-time communication between the system and the cloud server. The transmitted data is stored in the cloud database for monitoring and analysis.

Users can access the data remotely through a web application or mobile device.

4.5 Data Monitoring and Analysis

The cloud platform displays the received data in the form of graphs and numerical values. This allows users to monitor water quality from any location. If any parameter exceeds the safe limit, necessary action can be taken immediately.

This real-time monitoring system improves efficiency, reduces manual effort, and ensures safe water quality.

4.5 Working Principle

The overall working of the proposed system follows these steps:

1. Sensors measure water quality parameters.

2. ESP32 collects sensor data.
 3. ESP32 processes and converts the data.
 4. ESP32 transmits data to the cloud via Wi-Fi.
 5. Cloud platform stores and displays the data.
 6. User monitors data remotely in real time.
1. Macro minerals: Calcium, phosphorus, magnesium, sodium, potassium (required in larger amounts)
 2. Micro minerals, Iron, zinc, copper, manganese, iodine, selenium (required in smaller amounts)
 3. Electrolytes: Sodium, potassium, calcium, magnesium (carry electric charge)
 4. Heavy metals: Lead, mercury, arsenic, cadmium (toxic)

So, you've got contaminated water, and you want to make it clean. There are a few ways to do this, but one common method is using chemicals. Think of it like a big filter that removes the bad stuff.

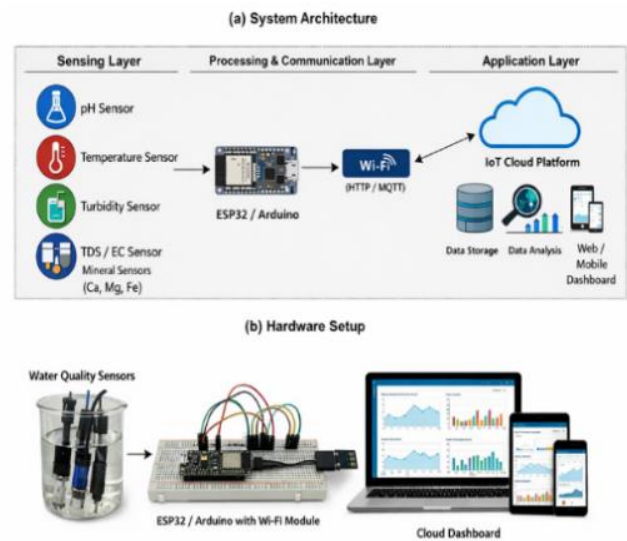
4.6 How it works:

1. Coagulation and Flucidation: They add chemicals like Alum or Ferric Chloride to make the contaminants stick together, making it easier to remove them.
2. Disinfection: They use Chlorine, Chloramine, or Ozone to kill off any nasty bacteria or viruses.
3. pH Adjustment: They add Lime or Soda Ash to balance out the water's pH levels, making it safe for drinking.
4. Heavy Metal Removal: They use Activated Carbon, Ion Exchange Resins, or special chemicals to remove heavy metals like lead or mercury.

4.7 Specific problems, specific solutions:

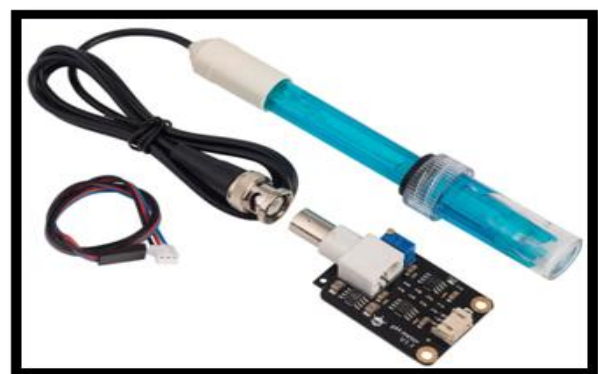
1. Iron and Manganese: They use oxidizing agents like Chlorine to remove these metals.
2. Nitrate and Phosphate: They use Ion Exchange Resins or biological treatment methods to remove these contaminants.

3. Heavy Metals: They use chemicals like Sodium Sulfide or Ferrous Sulfate to remove heavy metals.



4.8 Hardware and software requirement:

pH sensor: The pH of a solution is the measure of the acidity or alkalinity of that solution. The pH scale is a logarithmic scale whose range is from 0-14 with a neutral point being 7. Values above 7 indicate a basic or alkaline solution and values below 7 would indicate an acidic solution. It operates on 5V power supply and it is easy to interface with arduino. The normal range of pH is 6 to 8.5



1. **Glass Electrode:** A pH sensor typically consists of a glass electrode sensitive to hydrogen ions (H+).
2. **Reference Electrode:** A reference electrode provides a stable voltage reference.
3. **Voltage Measurement:** The pH sensor measures the voltage difference between the

glass electrode and reference electrode, which is proportional to the pH level.

Turbidity sensor: Turbidity is a measure of the cloudiness of water. Turbidity has indicated the degree at which the water loses its transparency. It is considered as a good measure of the quality of water. Turbidity blocks out the light needed by submerged aquatic vegetation. It also can raise surface water temperatures above normal because suspended particles near the surface facilitate the absorption of heat from sunlight.



Fig: Turbidity sensor

Temperature sensor: Water Temperature indicates how water is hot or cold. The range of DS18B20 temperature sensor is -55 to +125 °C. This temperature sensor is digital type which gives accurate reading.

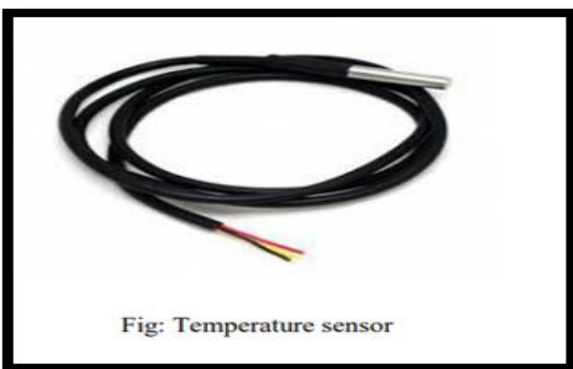


Fig: Temperature sensor

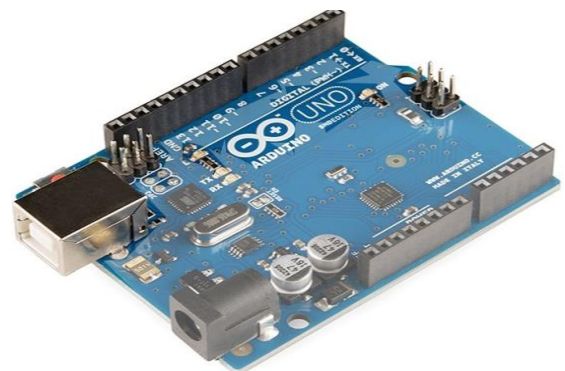
Flow sensor: Flow sensor is used to measure the flow of water through the flow sensor. This sensor basically consists of a plastic valve body, a rotor and a Hall Effect sensor. The pinwheel rotor rotates when water / liquid flows through the valve and its speed will be directly proportional to the flow rate. The Hall Effect

sensor will provide an electrical pulse with every revolution of the pinwheel rotor.



Fig: Flow sensor

Arduino Uno: Arduino is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller. Arduino Software (IDE) were the reference versions of Arduino, now evolved to newer releases. The Uno board is the first in a series of USB Arduino boards, and the reference model for the Arduino platform; for an extensive list of current, past or outdated boards see the Arduino index of boards.



Wifi module: The ESP8266 WiFi Module is a self contained SOC with integrated TCP/IP protocol stack that can give any microcontroller access to your WiFi network. The ESP8266 is capable of either hosting an application or offloading all Wi-Fi networking functions from another application processor. Each ESP8266 module comes pre-programmed with an AT command set firmware. The ESP8266 module is

an extremely cost effective board with a huge, and ever growing, community.

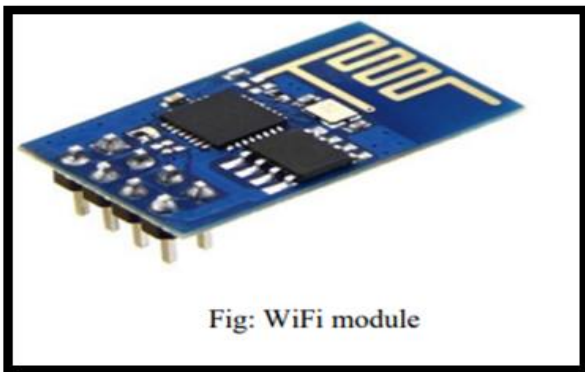


Fig: WiFi module

Water quality monitoring is crucial for ensuring safe drinking water and environmental sustainability. An IoT-based system is proposed for real-time detection of minerals like nitrate and phosphate, which can contaminate water sources. The system comprises sensors (pH, turbidity, TDS, and specific ion sensors) connected to an ESP32 microcontroller, which collects and processes data before transmitting it to a cloud platform via Wi-Fi. This enables users to monitor water quality remotely and receive alerts if parameters exceed safe limits. The system's real-time monitoring capabilities facilitate early detection of water contamination, allowing for prompt action to ensure safe drinking water and environmental protection. Additionally, the system's data analytics capabilities can help identify trends and patterns in water quality, informing water management strategies and policy decisions. The proposed system is cost-effective, reliable, and suitable for various applications, including domestic water monitoring, industrial usage, and environmental monitoring.

4.9 Current Water Quality Monitoring Systems:

Traditional water quality monitoring systems typically involve collecting water samples from various sources and sending them to a lab for analysis. This process can be time-consuming and may not provide real-time data.

Limitations

1. Time-consuming: Lab analysis can take days or even weeks, making it difficult to respond quickly to water quality issues.
2. Limited data: Sampling frequency and location may not capture all water quality variations.
3. Costly: Lab analysis and manual sampling can be expensive.

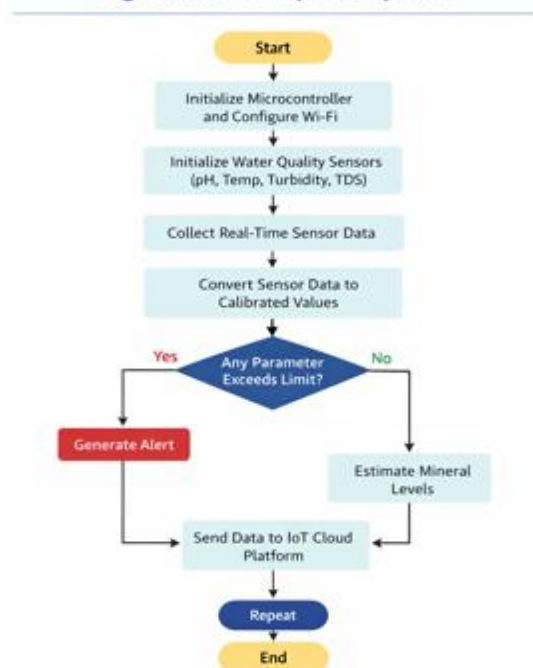
Existing IoT-based Systems:

Some existing IoT-based water quality monitoring systems use sensors to collect data on parameters like pH, turbidity, and TDS. These systems can provide real-time data and alerts, enabling quicker response times.

Examples:

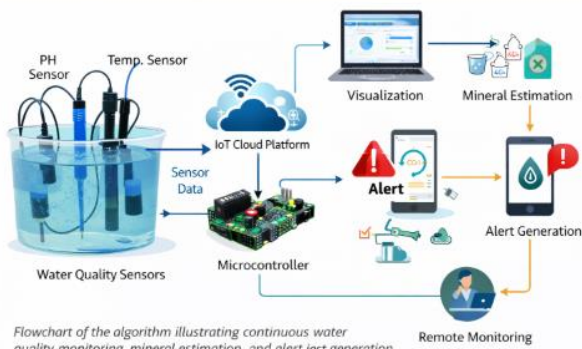
1. Wireless Sensor Networks: Systems using wireless sensors to collect data on water quality parameters.
2. Cloud-based Platforms: Systems using cloud-based platforms to collect, analyze, and visualize water quality data.

Algorithm for Proposed System



Flowchart of the algorithm illustrating continuous water quality monitoring, mineral estimation, and alert generation.

Proposed IOT-Based Water Quality Monitoring System



5. Conclusion

This paper presents the design and implementation of an IoT-enabled smart water quality monitoring system using the ESP32 microcontroller for real-time measurement and analysis. The proposed system continuously monitors important water quality parameters such as pH, turbidity, and temperature using appropriate sensors. The ESP32 microcontroller collects the sensor data and transmits it to an online platform through its built-in Wi-Fi capability, enabling real-time monitoring and remote access.

The developed system overcomes the limitations of traditional manual monitoring methods by providing automated, continuous, and efficient water quality monitoring. It reduces human effort, minimizes monitoring time, and allows users to detect water contamination at an early stage. The system is cost-effective, reliable, and suitable for various applications such as domestic water monitoring, industrial usage, and environmental monitoring.

In the future, the system can be enhanced by adding more sensors to measure additional parameters such as dissolved oxygen and conductivity. It can also be integrated with alert systems to notify users when water quality exceeds safe limits. Therefore, the proposed IoT-based water quality monitoring system provides an effective solution for ensuring safe and sustainable water management.

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