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Real-time Water Quality Analysis Using Fuzzy Logic

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Abstract

Nowadays the availability of safe drinking water is very difficult. In our project we are analysing water quality using different parameters like pH, turbidity, temperature and TDS for determining its safety level by monitoring the data from the readings. Moreover, we have a monitoring system for the data and also a webpage where all the data from these system is displayed. The sensors are connected to an Arduino Nano microcontroller and the Fuzzy Logic system is embedded in the microcontroller for the determination process. The output module contains an active buzzer, TFT display and a webpage interface with AI driven remedial measures. We transfer all the data to cloud and clients can access the quality *level through webpage, they can handle the data from anywhere whenever they need. Moreover, the project is portable and therefore, it can be carried everywhere as a plus point. It can be used for measuring all kinds of drinking water to ensure the safety level. In our project, we analyze water quality using different parameters such as pH, turbidity, temperature, and Total Dissolved Solids (TDS) to determine its safety level by continuously monitoring sensor readings. The sensors are connected to an Arduino Nano microcontroller, where a Fuzzy Logic system is embedded to process the collected data and accurately classify the water quality. This intelligent decision-making approach provides more flexible and reliable results compared to conventional threshold-based methods. The output module consists of an active buzzer, a TFT display, and a webpage interface that presents the measured values along with AI-driven remedial measures. The buzzer alerts users whenever unsafe water conditions are detected, while the display provides instant on-site information. The webpage enables users to monitor water quality remotely and access historical data for better analysis and decision-making. Furthermore, all sensor data is securely transferred to the cloud, allowing clients to access the water quality status anytime and from anywhere. Cloud storage also supports long-term data analysis and trend monitoring, making the system suitable for residential, industrial, and community water management applications. The project is portable, lightweight, and easy to deploy in different locations. It can be used to measure various types of drinking water sources, ensuring safe consumption while promoting public health and supporting smart water quality management.*

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INTRODUCTION

The availability of safe drinking water is one of the major health concerns in the world today. Millions of people die each year from water-borne diseases across the world due to contaminated water sources such as lakes, rivers, ponds, etc. In developing countries like India, a major part of the water which is used by people for daily consumption is stored in water tanks installed within residential buildings, institutions, and industrial establishments. There are many water purification systems which are widely used to purify water, but the quality of water stored is not monitored in many cases. The water may become contaminated with micro-organisms such as algae, bacteria, etc. as well as dissolved substances during storage if the storage tanks are not maintained properly. Usually, water is tested for purity and safe consumption using various conventional water testing techniques, which involve processes such as manual sampling and laboratory analysis but this process is considered quite time consuming and costly.

Moreover, the water test results are available only after a certain period of time and cannot be obtained immediately after contamination. Advancements in embedded systems and sensor technology have enabled the creation of smart monitoring systems, enabling real-time data to be obtained. It is possible to monitor water parameters in real time and detect any abnormality in the system immediately. The project titled "Real-Time Water Quality Analysis Using Fuzzy Logic" aims to create a smart real time monitoring system to assess water quality using various parameters. It aims to create a system using a fuzzy logic algorithm to determine the level of purity in the water and also includes an efficient power management system [1].

LITERATURE SURVEY

1. P. B. Bokingkito and L. T. Caparida, "Water quality assessment monitoring system using fuzzy logic and the Internet of Things," Media Elekt. Voice, vol. 14, no. 2, pp. 115–128, Dec. 2023.

- Bokingkito and Caparida propose an IoT-enabled fuzzy-logic water quality monitoring system that continuously acquires multi-sensor data and classifies water status into "good," "moderate," and "unhealthy." Their work demonstrates how fuzzy sets and rule-based inference efficiently handle uncertainty in sensor readings while providing interpretable linguistic outputs for decision makers. The system emphasizes remote access and real-time visualization, showing that an integrated fuzzy–IoT architecture can serve as a practical decision-support tool for proactive water management, very similar in concept to the proposed real-time analysis system.

2. H. M. Forhad, M. I. H. Bhuiyan, M. T. Rahman, S. Sadi and M. S. Islam, "IoT based real-time water quality monitoring system in water treatment plants," Heliyon, vol. 10, no. 23, Art. no. e41629, Nov. 2024.

- Forhad et al. developed an IoT-based monitoring platform for water treatment plants that continuously measures pH, dissolved oxygen, TDS, and temperature using networked sensors connected to a cloud backend. Their system provides real-time alerts, historical data logging, and remote supervisory control, thereby improving operational efficiency and enabling early detection of quality deviations. This work underlines the importance of remote access, data logging, and alarm mechanisms—features that align closely with the ESP32-based web interface and alerting functions in the present project [2].

3. Y. Barzegar, I. Gorelova, F. Bellini and F. D'Ascenzo, "Drinking water quality assessment using a fuzzy inference system method: A case study of Rome (Italy)," Int. J. Environ. Res. Public Health, vol. 20, no. 16, Art. no. 6533, Aug. 2023.

- Barzegar et al. design a hierarchical Mamdani fuzzy inference system that aggregates nine physicochemical parameters—such as alkalinity, hardness, pH, major ions, and nutrients—to predict an overall drinking water quality index for Rome. Their model uses multiple intermediate fuzzy layers and 27 rules to address nonlinearity and uncertainty in water quality assessment, showing that fuzzy logic is well suited for complex, multi-parameter evaluation. The methodology provides a conceptual basis for defining membership functions, rule bases, and defuzzification strategies in the proposed fuzzy-logic controller for real-time monitoring.

4. "Water Quality Monitoring System Based on Fuzzy Algorithm," Int. J. Adv. Sci. Eng. Inf. Technol., vol. 12, no. 5, pp. 2010–2017, Oct. 2022.

- This study presents a prototype fountain-water monitoring device that uses pH and turbidity sensors connected to an Arduino Nano, where a Tsukamoto fuzzy algorithm determines whether the output solenoid valve should open or close. The system defines three membership functions for each parameter and derives nine fuzzy rules, which are experimentally validated across different water conditions such as clean, slightly cloudy, and dirty. Its use of Arduino-based fuzzy processing and discrete valve control closely parallels the proposed system's use of Arduino Nano and fuzzy rules for classifying water as acceptable, ideal, or unsafe.

5. "Water quality assessment monitoring system using fuzzy logic and the internet of things," Media Elekt. Voice, vol. 14, no. 2, pp. 115–128, 2023.
- This article integrates a fuzzy decision engine with distributed IoT sensor nodes to provide continuous, remote assessment of water suitability. The authors show that by categorizing outputs into intuitive levels—good, moderate, and unhealthy—the system enables stakeholders to respond quickly to degradation in quality while tolerating noisy measurements. Their architecture, combining remote sensing, wireless communication, and fuzzy-based categorization, strongly supports the design choices in the current project, especially the use of membership functions to encode acceptable and ideal ranges over temperature and other parameters.

6. "IoT-Enabled Real-Time Monitoring and Tsukamoto Fuzzy Inference for Intelligent Water Quality Management," J. Tek. Inform. Elektro, vol. 6, no. 2, pp. 118–130, 2024.
- This work employs the Tsukamoto fuzzy logic method in an IoT-enabled monitoring framework, where sensor data are mapped through monotonic membership functions and a structured rule base to produce crisp water suitability scores. The system demonstrates how fuzzy inference can be deployed at the edge to support local decision-making, while IoT connectivity enables centralized visualization and analysis. Such a combination of on-device fuzzy computation and networked interfaces is directly relevant to the proposed architecture using Arduino Nano for inference and ESP32 for web-based monitoring [3].

Problem Definition

The increasing rate at which contaminants are entering our water supplies, in combination with the slow and expensive process by which we check for them, makes it difficult to ensure that people all over the world have access to safe and clean drinking water. The conventional method for testing our water is carried out in a laboratory setting. The process can be expensive and slow and does not offer real-time results. The delay in the process makes it difficult for some contaminants such as high concentrations of dissolved and suspended solids and microorganisms to be detected in a timely manner. In addition, some processes fail during a power outage. We need a robust and efficient monitoring system that offers real-time results for the maintenance of drinking water quality for people in different regions [4].

Problem Solution

The solution that is being proposed is an intelligent and real-time water quality monitoring system. The solution makes use of a combination of multi-parameter sensing, fuzzy logic decision-making, and IoT technology for communication in a way that is effective in determining the safety of the water. The parameters that need to be kept track of in real-time include pH value, turbidity, temperature, and total dissolved solids. The data collected from these sensors is processed by a fuzzy inference system that enhances the accuracy of water quality assessment by skillfully managing uncertainties. The system is also robust and capable due to the use of a dual-microcontroller configuration. One microcontroller is responsible for handling the communication and processing tasks, while the other is responsible for communication with a web server. The system also has an alerting system that makes use of a display and buzzer. The power management unit makes use of an AC adapter and a lithium-ion battery to ensure that the system remains in continuous operation. Such a system is a holistic and efficient way in which water quality can be monitored [5].

SYSTEM DESIGN

Block Diagram

The block diagram given in Figure 1, shows the architectural setup of the water-quality monitoring system. The architecture is divided into the following parts: Firstly, we have the four major sensors used to measure the various parameters such as acidity, alkalinity, etc. using mainly: pH, turbidity, TDS and temperature sensors. Secondly, we have an Arduino Nano microcontroller that collects the raw data from the sensors and uses Fuzzy logic classification algorithm to classify the water quality into different levels for making more flexible and accurate decisions rather than using fixed thresholds to assess the water quality. The Arduino Nano microcontroller sends the raw data to the second microcontroller via the UART interface. There is a logic converter that manages the voltage levels between the first microcontroller and the second microcontroller in order to prevent any damage from occurring to the second microcontroller ESP-32. Thirdly, the ESP-32 microcontroller receives the classified data from the first microcontroller via the logic converter and uploads this information to a web server, enabling remote monitoring through a web interface. For local alerts, a TFT display and a variable intensity buzzer are used.

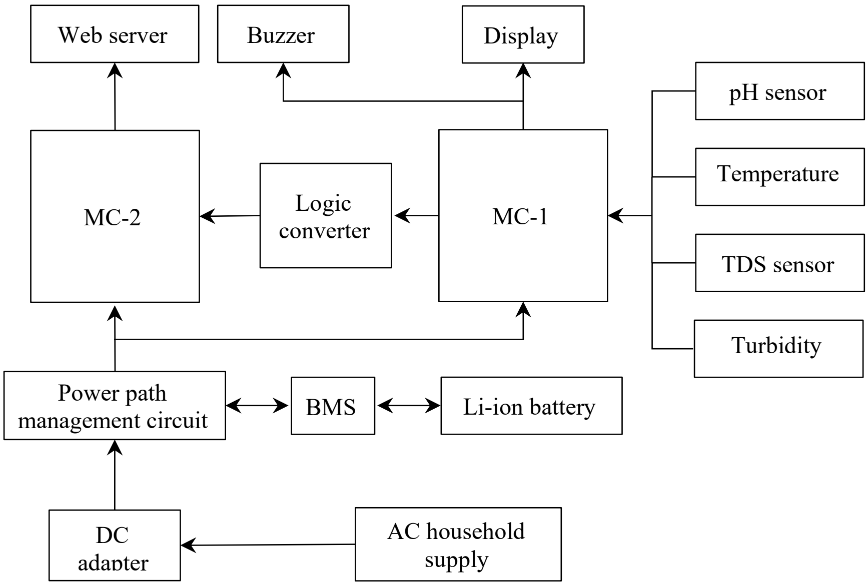

Figure 1. Block diagram.

There is also a web server to store the data from the ESP-32 microcontroller and display it on a user-accessible web interface. This provides for real-time monitoring of water quality and it also gives AI-driven suggestions and instructions to the end user. The system draws power through the adapter and the power management system consists of Li-ion battery, BMS module, UPS module and charging module which are provided to ensure the system operates throughout the day even during power outages [6].

Circuit Diagram

The circuit diagram given above in Figure 2 indicates a smart water quality monitoring system that senses various parameters of the water and displays the results while simultaneously transmitting the results. The central controller of the entire system is the Arduino Nano microcontroller. It collects various signals from the sensors used in the analysis of the quality of the water. The turbidity sensor, analog pH sensor, and TDS (Total Dissolved Solids) sensor are connected to the analog input of the Arduino microcontroller. These sensors measure the clarity of the water, acidity or alkalinity of the water, and the amount of dissolved matter in the water. A digital temperature sensor, the DS18B20 Temperature Sensor, is also connected with the microcontroller to measure the temperature of the sample of the water, which plays an important role in the quality of the water. The data collected from these sensors is processed using an Arduino Nano board and displayed on a TFT display module. Using these modules, the user can monitor the real-time values of different parameters of the water. A buzzer module is also used in the circuit. It generates an alert message whenever the values of the parameters are high, reflecting poor quality of the water. For the purpose of wireless communication in the circuit, an ESP32 module is used. Since the Arduino Nano board and the ESP32 module work at different logic voltage levels, a logic level shifter module is used in the circuit. It ensures safe communication between the modules. The circuit is powered using a Li-ion battery. It is connected to the circuit using a battery management system and a battery charging module. A voltage regulation module of 5V and 3.3V is used in the circuit. It provides the necessary voltages required by the microcontroller in the circuit [7].

METHODOLOGY

Fuzzy Logic

The fuzzy logic algorithm used in the water quality monitoring system helps in making intelligent decisions regarding the safety of the water. It does this by analyzing the values obtained from various sensors used in the process. In the water quality monitoring system, parameters such as pH value, turbidity, temperature, and total dissolved solids (TDS) are continuously monitored using sensors and sent to the microcontroller, which in this case may be Arduino Nano. These parameters represent the characteristics of the water in terms of its physical and chemical composition. However, interpreting these values may not always give an accurate result. Hence, a fuzzy logic algorithm is used in the process. As shown in table 1, it does not use a true or false condition in its process. It uses a partially true condition and categorizes the parameters of the sensors in terms of low, medium, or high values using membership functions as shown in Figure 3, Figure 4, Figure 5 and Fig 6. Lastly, in the defuzzification stage, the fuzzy output values are mapped to a single crisp value that represents the entire status of the water quality. This final output will show if the water is safe, moderately contaminated, or if it is not safe [8].

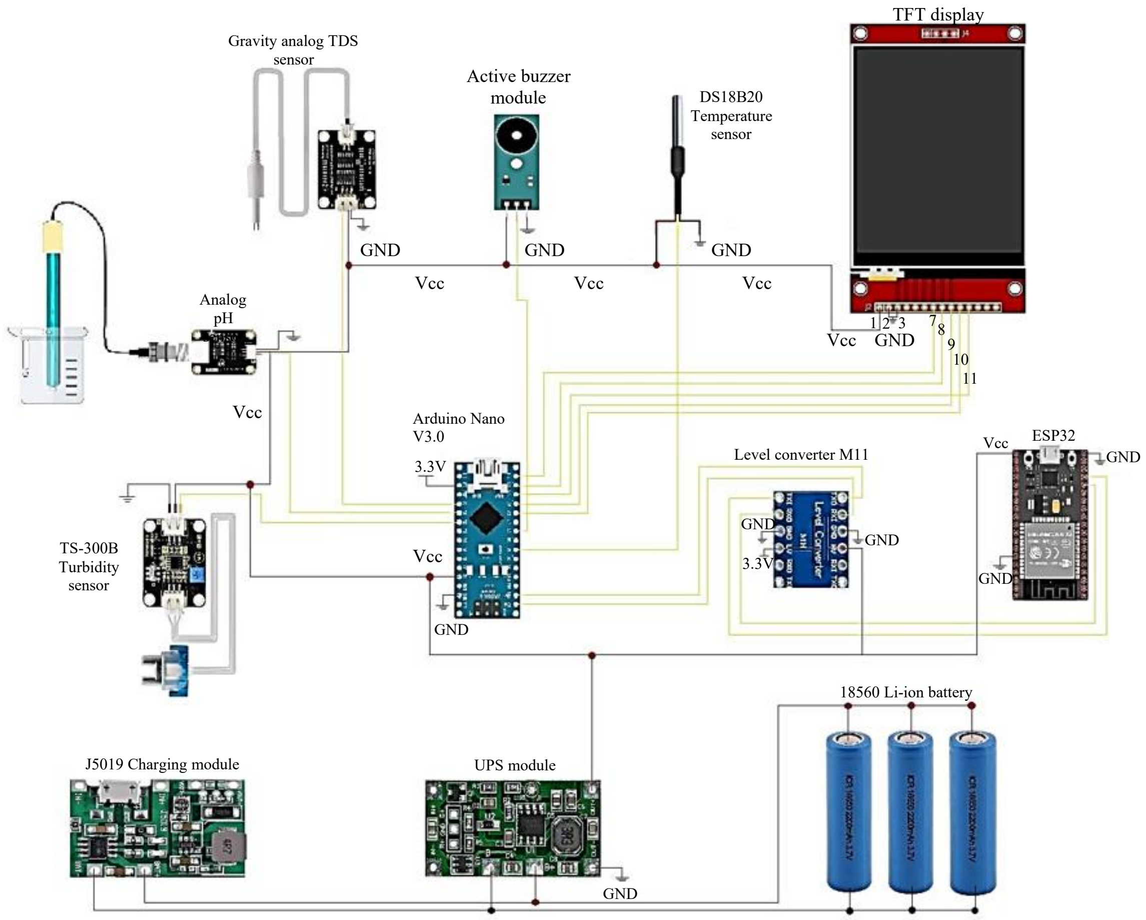

Figure 2. Circuit diagram.

The processed output may be displayed on the graphical display module and sent wirelessly using the wireless communication module, which is the ESP32-WROOM-32 module. Additionally, the fuzzy logic system will be able to trigger the buzzer if it detects that the water is not safe. Therefore, the fuzzy logic system will enhance the accuracy of the water quality monitoring system and make it more reliable and appropriate for use in environmental monitoring.

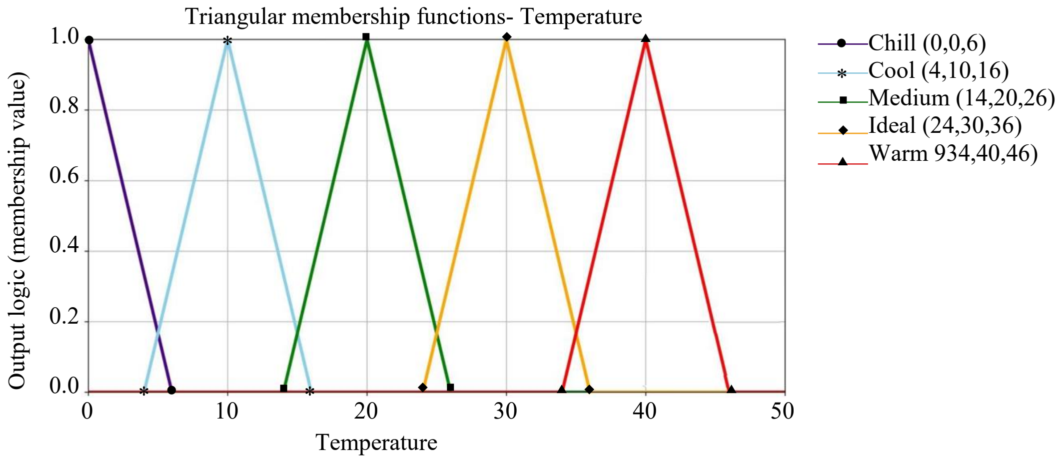

Figure 3. Sample membership functions for temperature.

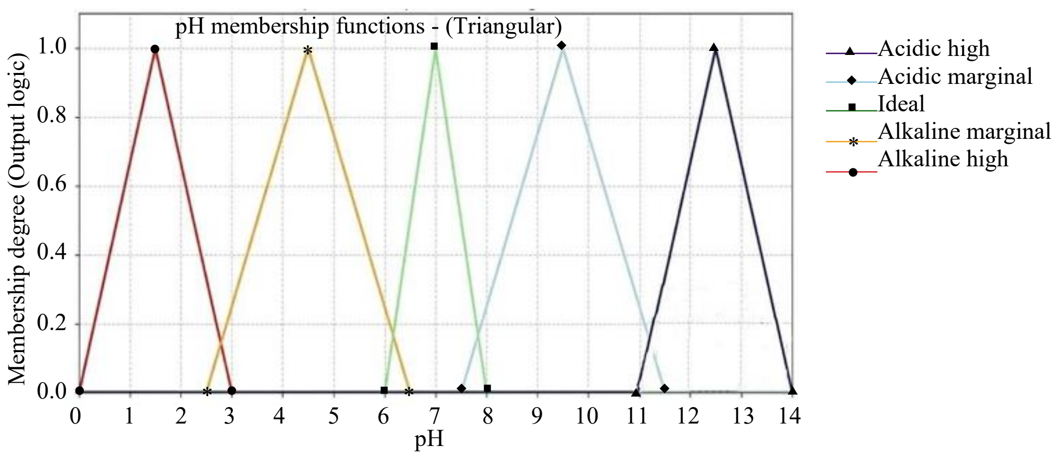

Figure 4. Sample membership functions for pH.

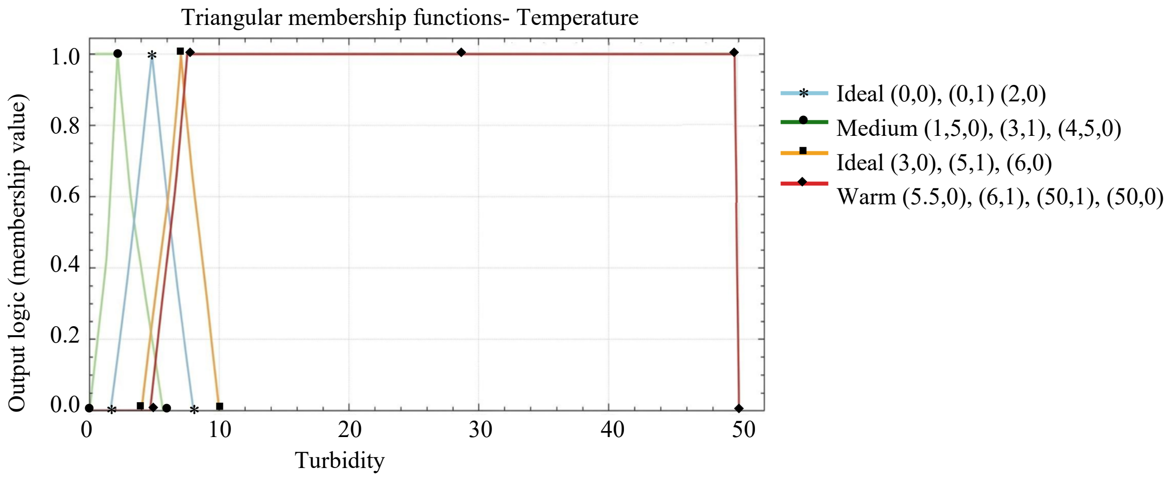

Figure 5. Sample membership functions for turbidity.

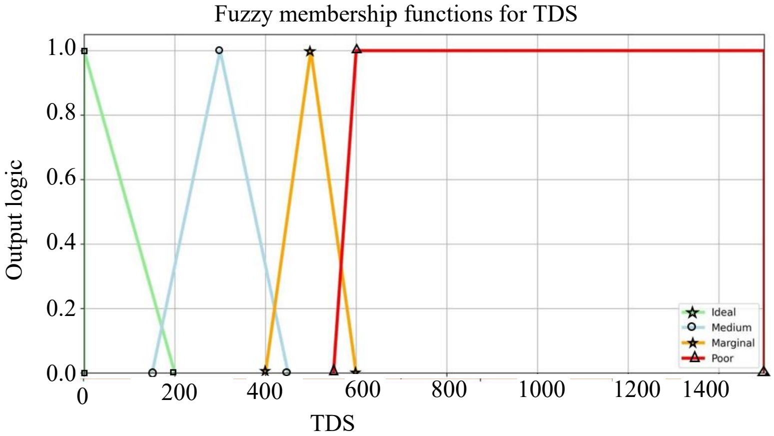

Figure 6. Sample membership functions for TDS.

Table 1. Fuzzy logic ruleset.

Rule	pH	Turbidity	TDS	Quality
R1	Neutral	Low	Low	Good
R2	Neutral	Low	Medium	Moderate
R3	Neutral	Low	High	Poor
R4	Neutral	Medium	Low	Moderate
R5	Neutral	Medium	Medium	Moderate
R6	Neutral	Medium	High	Poor
R7	Neutral	High	Low	Poor
R8	Neutral	High	Medium	Poor
R9	Neutral	High	High	Poor
R10	Acidic	Low	Low	Moderate
R11	Acidic	Low	Medium	Moderate
R12	Acidic	Low	High	Poor
R13	Acidic	Medium	Low	Moderate
R14	Acidic	Medium	Medium	Poor
R15	Acidic	High	Any	Poor
R16	Alkaline	Low	Low	Moderate
R17	Alkaline	Medium	Medium	Poor
R18	Alkaline	High	Any	Poor

Workflow

The first step in this process according to the flowchart given in Figure 7 is sensor data acquisition, in which the primary microcontroller (MC-1) is constantly in contact with four important sensors to collect information about water quality parameters. The pH sensor is used to detect the acidity or alkalinity of water, and its range is 0-14. It is used to detect the hydrogen ion concentration in water, where 7 is the neutral value. TDS sensor is used to detect the amount of minerals, salts, and metals present in water, and this is done by detecting the conductivity of water. The turbidity sensor is used to detect the clarity of water, and this is done by detecting the amount of scattering of light in water using an LED and a photo diode. When water is clear, it allows much light to pass, but when it is cloudy, much light is scattered. The Dallas DS18B20 temperature sensor is also used to obtain accurate temperature values in digital format with a tolerance of ±0.5°C using the 1-Wire protocol, as temperature is an important parameter in water chemistry.

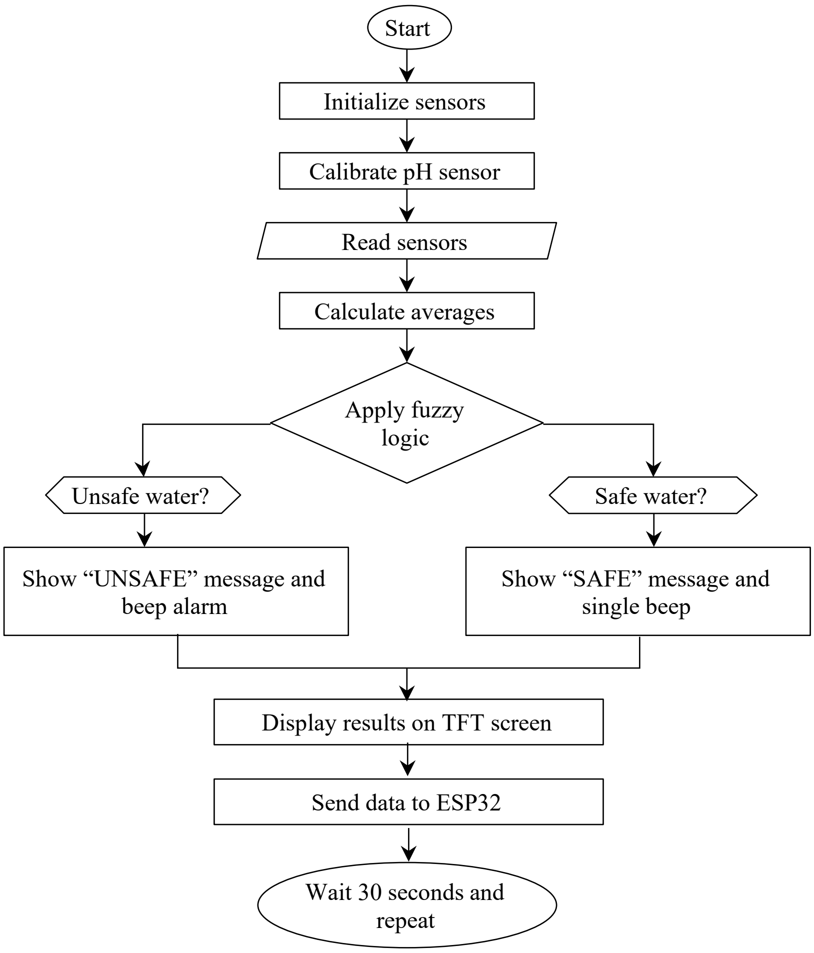

Figure 7. Flowchart representation of the workflow.

Once the sensor data is acquired, it is then sent to MC-1, which processes and classifies it using fuzzy logic. Fuzzy inference system: It determines the level of safety or risk by matching the sensor data with predefined datasets. It gives a classification result that determines the water quality status at any given time. It runs continuously to provide immediate response to any change in water quality. Local Alert System: It is activated based on the results obtained from the fuzzy logic classifier. MC-1 controls a display unit that displays the water quality level at any given time. It gives users immediate feedback on water quality. At the same time, a buzzer system is activated with varying intensity according to the level of risk. If water quality is good, the buzzer is off or has low intensity. If water quality deteriorates with an increase in contaminants, the intensity of the buzzer increases to provide feedback to users. It alerts users to an increase in contaminants through an increase in buzzer intensity [9].

Inter-Microcontroller Communication: MC-1 sends the classified water quality data and associated raw sensor data to MC-2 through asynchronous UART serial communication. A logic level converter is used to connect MC-1 and MC-2. It ensures that there is no communication problem or damage to the devices due to differing signal voltages. It is responsible for providing protocol compatibility and immunity to noise. The remote monitoring and web connectivity feature is implemented using MC-2. It receives water quality data from MC-1 and sends it to a web server after proper formatting. Users can view water quality monitoring data online using web browsers or mobile devices through a web platform. It not only displays data but also offers detailed analysis of data. It may even provide suggestions to users regarding corrective measures to be taken based on analysis of data trends. Users can view water quality from anywhere and get suggestions to activate water purification systems or adjust parameters accordingly. It is an adaptive system and becomes more intelligent with time. The power management system enables the continuous and uninterrupted operation of the system under any conditions. The system mainly uses the AC mains available in the home, which is then rectified to DC voltage and regulated with the help of an adapter. The power path management circuit switches the power supply between the AC mains connected to the adapter and the rechargeable lithium-ion battery backup [10].

The Battery Management System manages the switching and the charging and discharging of the battery. The BMS offers critical protection against overcharge, deep discharge, overcurrent, short circuits, and thermal conditions. During normal operation, with the AC mains connected, the adapter supplies the power and charges the battery with the help of the BMS. During power failures, the power path management circuit switches the power supply to the battery backup, and the system continues to operate normally without any interruption, thus avoiding data loss and the continuous monitoring of water quality. The whole process works as an integrated system with environmental sensing feeding into intelligent decision-making through fuzzy logic processing, providing detailed local alerts and remote monitoring capability while providing robust uptime through advanced power management. Such an approach is an all-encompassing solution to meet the critical need for continuous, reliable, and accessible water quality monitoring for various applications from domestic to industrial and municipal use. Such a dual-microcontroller-based system design isolates sensor handling and local alerting from cloud communication handling, allowing parallel operation and improving system reliability while allowing for cloud integration and ML analytics through a modular design without major redesign.

RESULT AND DISCUSSION

Webpage

The given image in Figure 8 is a representation of a Water Quality Monitoring System Using Fuzzy Logic. The purpose of this system is to analyze various parameters present in water and check whether the water is safe or suitable for use. This type of interface is commonly used in smart systems used for environmental monitoring. These systems include various sensors that collect data from water sources such as drinking water tanks, rivers, or industrial water systems. The dashboard is used to display the data collected from sensors in a visually appealing manner. After processing the data collected from various sensors, the system displays an easy-to-understand representation of the overall quality of water. The system is used to monitor water conditions and understand whether the water is suitable for use or not.

Figure 8: Webpage.

The top of the webpage has a title that indicates the purpose of the system. The system has a runtime indicator that shows the time that has elapsed since the system started running. The runtime indicator is important to ensure that users are able to comprehend that the system is running at all times. The system also has a connection status indicator that shows whether it is connected to the hardware device. In most monitoring systems, the sensors are connected to a microcontroller that sends data to the software interface. The system has a connection status indicator that shows whether it is connected to the hardware device. In case it is not connected, it waits until it is connected before it receives data.

The first major section of this webpage is the Sensor Data panel. This section shows data collected from various water quality sensors placed within the system. Each sensor detects a certain physical or chemical attribute of the water. Some of the parameters that are being detected include the pH level. This parameter measures how acidic or alkaline the water is. It is crucial to keep the pH level balanced because if it is too high or too low, it can impact human health or cause damage to equipment or living organisms. The total amount of dissolved solids is another parameter being detected. This refers to the total amount of minerals, salts, and organic matter that is present in the water. Too much of these substances can impact how safe or how desirable the water is for drinking or other purposes.

The webpage has an additional feature called AI Interpretation. This feature is intended to give an intelligent explanation or interpretation of the information from the sensor. The intelligent component is able to interpret various patterns from the information collected by the sensor and give meaningful interpretations regarding the condition of the water. For instance, it could explain possible reasons for changes in water quality or give recommendations on how to improve the condition of the water. This feature is important in enhancing the monitoring system to give users information regarding the condition of the water through intelligent explanations or interpretations of the information from the sensor.

At the bottom of the webpage is a statement that indicates that the system utilizes true fuzzy logic to evaluate all parameters. This indicates that the monitoring system does not solely rely on individual parameters to assess the quality of the water. Instead, it considers the interaction between various parameters to assess the quality of water. The system is important in modern environmental management because it is able to monitor water quality through various parameters and ensure effective protection of water resources.

CONCLUSION

The proposed Real-Time Water Quality Analysis System using fuzzy logic provides an efficient and intelligent solution for the continuous monitoring of water quality. The system utilizes four essential sensors mainly: pH, TDS, turbidity, and temperature sensors to evaluate various water conditions. The data from the sensors get processed using a fuzzy logic algorithm which is implemented on the Arduino Nano microcontroller which allows flexible decision-making compared to other fixed threshold-based systems. The integration of ESP32 microcontroller is used for facilitating remote monitoring via web server and it also provides local alerts through a display and a buzzer. Additionally, we have also included a battery management system for ensuring the uninterrupted operation of the system even during power outages. Overall, this real-time water quality monitoring system offers a reliable, intelligent as well as cost-effective solution for ensuring the safety and quality of water across households, institutions, and industrial applications.

To guarantee uninterrupted operation, the system includes a dedicated battery management module with charging circuits, low-battery detection, and automatic switching between mains power and backup lithium-ion batteries. This feature proves invaluable in remote or off-grid locations, preventing data loss during power outages common in regions like rural Kerala. Overall, this system stands out as a reliable, scalable, and cost-effective platform for water safety assurance in households, educational institutions, hospitals, and industrial settings. By combining fuzzy intelligence with IoT capabilities, it not only detects issues proactively but also supports data logging for regulatory compliance and longterm trend analysis, paving the way for predictive maintenance and sustainable water resource management.

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