Adaptive Edge Water Quality Analytics System

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Abstract - Water pollution is one of the biggest fears for the green globalization as water is a fundamental resource essential for life, ecosystems and socio-economic development. The increasing industrialization, urbanization, and agricultural activities have contributed to widespread water pollution, raising serious concerns about water quality. The paper proposes design and development of low cost water quality monitoring system used to measuring the parameters such as temperature, PH, turbidity, flow sensor of the water for safe for drinking water. The approached result concludes with water sample 1's temperature 20°C, pH 7.5, and turbidity 1 NTU are all within permissible limits and is safe for drinking water. The water sample 2 exhibits turbidity 5 NTU at the highest permitted threshold and pH 9.3, higher than the permissible limit and temperature of 29.4°C is unsafe to consume because of its high pH. The water sample 3 has excessive acidity with a pH of 4.1, turbidity of 4 NTU and temperature of 26.4°C are within acceptable bounds and makes it unfit for human consumption.

Key words; Turbidity, Nephelometric, MQTT, HTTP

I. INTRODUCTION

In the 21st century, there were lots of inventions, but at the same time were pollutions, global warming and so on are being formed, because of this there is no safe drinking water for the world's pollution. The significance of water quality monitoring extends across various domains. For public health, it ensures compliance with safety standards and prevents waterborne diseases. In industrial applications, it helps monitor effluents and supports regulatory compliance. In agriculture and aquaculture, it ensures that water quality is suitable for irrigation and fish farming. Additionally, it plays a vital role in environmental conservation by preventing the degradation of aquatic ecosystems. Despite its importance, conventional water monitoring methods have inherent limitations, such as limited coverage, delayed results, and high costs, which can be effectively addressed through IoT-based solutions. The internet has become a common interface that many devices use in order to simplify the daily life of many people giving the ability to search for information, store their own information in the cloud while also giving them better ways of managing information. From the time of its introduction, the number of people that use mobile phones and the internet to communicate with other people has increased dramatically to become one of the major means of communication. Nowadays, water quality monitoring in real time faces challenges because of global warming limited water resources, growing population, etc. Hence there is need of developing better methodologies to monitor the water quality parameters in real time. In an IoT-based water quality monitoring system, sensors are deployed to measure key parameters such as pH, turbidity, temperature, dissolved oxygen, and electrical conductivity. These sensors are integrated with communication modules that transmit data to a centralized platform, often hosted on cloud-based systems. Advanced analytics, dashboards, and mobile applications enable real-time monitoring, predictive insights, and remote accessibility. IoT based water level monitoring and controlling systems are new and upcoming technology in residential and commercial sectors that have many benefits in terms of electricity and environment.

A comparison is made on manual and IoT based system in terms of power consumption and wastage of water. Now with the advent of Machine-to-Machine Communication which leads to devices communicating among themselves and accordingly analyzing the data intelligently, here we have developed an "IoT Based Water Level Monitoring System using". The controller-based Water level monitoring is used to indicate the level of water in the tank to agent. Sensor Based Water Level Detection, it will check the water by using water level sensors. This approach overcomes the challenges of traditional methods by providing continuous monitoring, reducing operational costs, and minimizing the risk of human error.

The old IoT-based water quality monitoring systems were often characterized by limited hardware and software capabilities. These systems generally used basic sensors, which could only measure a small set of parameters such as pH, turbidity, temperature, and conductivity. These sensors were often susceptible to drift over time, requiring frequent calibration. Additionally, the data transmission was frequently done through less efficient communication technologies like GSM or Wi-Fi, which posed issues in terms of energy consumption, range, and reliability, particularly in rural or remote areas. The data was typically uploaded to centralized servers or local databases, but the lack of integrated analytics and processing power meant that data analysis was often performed manually or with minimal automation, limiting the potential for real-time decision-making. In contrast, modern IoT-based water quality monitoring systems integrate state-of-the-art sensors with significantly improved accuracy and sensitivity. These systems not only measure traditional parameters but also include advanced sensors for detecting specific pollutants such as nitrates, phosphates, heavy metals, and even microbial contamination. The modern sensors are more durable, require less maintenance, and offer enhanced calibration stability. Communication technologies like LoRa WAN, NB- IoT, and 5G have been adopted to provide low-power, wide-area connectivity, allowing these systems to function efficiently in remote or challenging environments with less need for infrastructure.

II. LITERATURE SURVEY

The author highlights the entire water quality monitoring methods, sensors, embedded design, and information dissipation procedure, role of government, network operator and villagers in ensuring proper information dissipation. The study also explores the sensor cloud domain. While automatically improving the water quality is not feasible at this point, efficient use of technology and economic practices can help improve water quality and awareness among people [1].

The author [2] describes the safe supply of drinking water quality should be monitored in real time for that purpose new approach IOT (Internet of Things) based water quality monitoring has been proposed. The design of IOT based water quality monitoring system that monitor the quality of water in real time. This system consists some sensors which measure the water quality parameter such as pH, turbidity, conductivity, dissolved oxygen, temperature. The measured values from the sensors are processed by microcontroller and this processed values are transmitted remotely to the core controller that is raspberry pi using Zigbee protocol. Finally, sensors data can view on internet browser application using cloud computing.

The paper describes the conjunction of the Smart City Initiative and concept of Industry 4.0. The smart city has been a phenomenon of the last years, which is very inflected especially since 2008 when the world was hit by the financial crisis. The main reasons for the emergence of smart city initiative are to create a sustainable model for cities and preserve quality of life of their citizens. The topic of the smart city cannot be seen only as a technical discipline, but different economic, humanitarian or legal of Things (IoT) shall be used for the development of so–called smart products. Sub components of the product are equipped with their own intelligence. Added intelligence is used both during the manufacturing of a product as well as during subsequent handling, up to continuous monitoring of the product lifecycle (smart processes). Other important aspects of the Industry 4.0 are Internet of Services (IoS), which includes especially intelligent transport and logistics (smart mobility, smart logistics), as well as Internet of Energy (IoE), which determines how the natural resources are used in proper way (electricity, water, oil, etc.). IoT, IoS, IoP and IoE can be considered as an element that can create a connection of the Smart City Initiative and Industry 4.0 – Industry 4.0 can be seen as a part of smart cities [3].

The author [4] explains an efficient energy management frame work to provide satisfactory QOI experience in IOT sensory environments is studied. Contrary to past efforts, it is transparent and compatible to lower protocols in use, and, the new concept of QOI-aware “sensor-to-task relevancy” to explicitly consider the sensing capabilities offered by a sensor to the IOT sensory environments, and QOI requirements required by a task. A novel concept of the “critical covering set” of any given task in selecting the sensors to service a task over time. Energy management decision is made dynamically at runtime, as the optimum for long-term traffic statistics under the constraint of the service delay. Finally, an extensive case study based on utilizing the sensor networks to perform water level monitoring is given to demonstrate the ideas and algorithms proposed in this paper.

The adaptive edge analytics for distributed networked control of water systems is presents the burst detection and localization scheme that combines lightweight compression and anomaly detection with graph topology analytics for water distribution networks. The approach not only significantly reduces the amount of communications between sensor devices and back end servers, but also can effectively localize water burst events by using the difference in the arrival times of vibration variations detected at sensor locations [5].

III. FRAME WORK FOR ADAPTIVE EDGE WATER QUALITY ANALYTICS

The issue of water pollution has become a critical global concern, directly impacting the availability of safe drinking water. Factors such as rapid industrialization, urbanization, population growth, and climate change have exacerbated the problem, leading to the contamination of water bodies and making it increasingly challenging to ensure water quality. Traditional methods for water quality monitoring rely on manual collection of samples and laboratory analysis, which are both time-consuming and resource-intensive. These approaches often fail to provide real-time data, which is crucial for timely intervention and management, especially in areas where water quality changes rapidly due to external factors. As a result, there is an urgent need for innovative, efficient, and cost-effective solutions to monitor water quality in real time.

The paper addresses the problem by presenting a design and development of water quality monitoring system based on Internet of Things. It is an emerging technology that integrates sensors, communication networks, and data processing to provide real-time monitoring and control. The proposed system uses multiple sensors to measure key physical and chemical parameters of water, such as pH, turbidity, temperature, and flow rate. These parameters are critical indicators of water quality, with pH determining acidity or alkalinity, turbidity indicating the presence of suspended particles, temperature affecting aquatic ecosystems, and flow rate ensuring adequate water movement.

The block diagram Fig.1 illustrates a water quality monitoring system using an ESP32 microcontroller. The system consists of three sensors: pH sensor to measure the acidity or alkalinity of water, a turbidity sensor to determine water clarity, and temperature sensor to monitor water temperature. The sensors transfer their data to ESP32 microcontroller, which processes the information. The processed data is displayed locally on an LCD display and simultaneously sent to the Blynk Dashboard via internet. The Blynk Dashboard serves as platform for remote visualization, enabling users to monitor water quality through a mobile app in real time. The system is powered by a dedicated power supply, ensuring continuous operation and seamless local and remote monitoring.

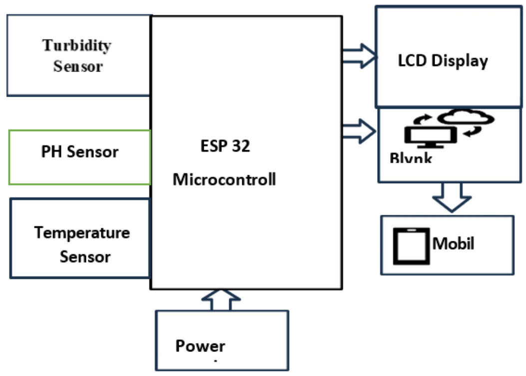


Figure.1 Frame work for Adaptive Edge Water Quality Analytics

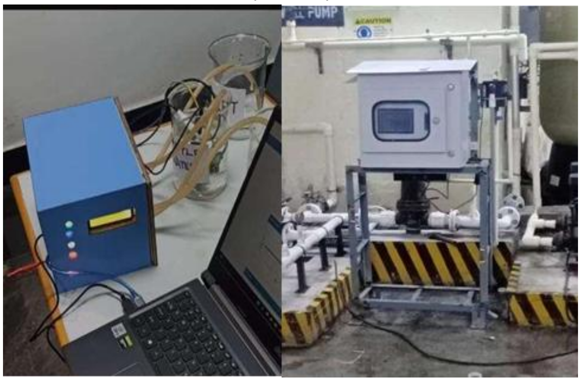


Figure.2 Real time water quality monitoring system

IV. METHODOLOGY TO DEMONSTRATE WATER QUALITY ANALYTICS

The methodology for developing IoT-based water quality monitoring system involves structured approach that integrates hardware components, software design, and IoT connectivity to achieve real- time and accurate monitoring of key water quality parameters. The algorithm is designed to include sensors for measuring water quality parameters such as pH, turbidity and temperature. An ESP32 microcontroller serves as the core processing unit, receiving data from sensors and converting analog signals into digital form. A Wi-Fi module (ESP32) is integrated to transmit sensor data to a cloud server for remote monitoring. Sensors collect water quality data: pH sensor measures the acidity/alkalinity. Turbidity sensor measures water clarity. Temperature sensor measures the water temperature. Microcontroller reads data from sensors, processes it, and displays it on the LCD. Sends it to the Blynk dashboard via Wi-Fi. Blynk Dashboard provides remote monitoring of the data

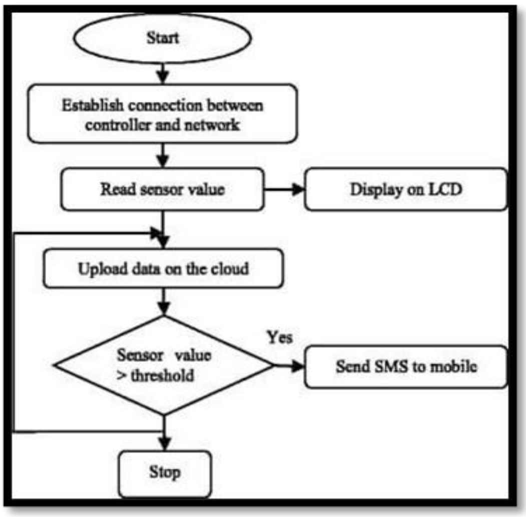


Figure.3.Algorithm to demonstrate water quality monitoring system

The IoT-based water quality monitoring system flowchart represents the seamless integration of sensors, data processing, communication, and user interaction. The process begins with the data collection stage, where advanced sensors are deployed to measure key water quality parameters such as pH, turbidity, temperature, dissolved oxygen, and electrical conductivity. These sensors act as the core components of the system, ensuring accurate and reliable measurement of water characteristics in real-time. The data collected from these sensors is often raw and may contain noise, which is addressed through signal conditioning techniques. This ensures that the measurements are clean and ready for processing, maintaining the integrity of the monitoring process. Once the raw data is conditioned, it is transmitted to a microcontroller or processing unit like an Arduino, Raspberry Pi, or ESP32, which serves as the system's central hub. This unit is responsible for organizing, analyzing, and formatting the sensor data before it is transmitted further. Connected to an IoT communication module, such as Wi-Fi, GSM, or LoRa, the microcontroller ensures the seamless transfer of data to a cloud-based platform or centralized server. Communication protocols like MQTT or HTTP enable real-time data transfer, ensuring that updates on water quality are sent promptly to the monitoring system. The integration of IoT technology ensures a robust and scalable communication process, even in remote areas.

Finally, the processed data is stored and visualized for end-user access. Cloud platforms or dedicated servers display the water quality metrics in an easy-to-understand graphical format on web or mobile applications. These user interfaces enable stakeholders, such as environmental agencies, researchers, or local authorities, to analyze trends, receive alerts on unsafe water conditions, and make informed decisions. Additionally, the system can trigger automated alerts via SMS, email, or push notifications in case of critical thresholds being crossed. The flowchart encapsulates the end-to-end workflow of this IoT-based water quality monitoring system, emphasizing real-time monitoring, automation, and user-friendly data access to ensure water safety and environmental sustainability.

V. EXPERIMENTAL RESULT AND ANALYSIS

The paper resulted in the successful development of a real-time IoT-based water quality monitoring system. It utilizes sensors to measure critical water parameters, including pH, turbidity, and temperature. These sensors are interfaced with an ESP32 microcontroller, which processes the data and displays it locally on a 16x2 LCD with an I2C adapter. Simultaneously, the data is transmitted via Wi-Fi to the Blynk IoT platform, allowing users to monitor water quality remotely using a mobile app or web dashboard. The system provides real-time visualization, remote accessibility. By automating water quality assessment, this system eliminates the need for traditional manual sampling, reducing costs and improving efficiency. This project offers a practical, scalable, and user-friendly solution to address water pollution concerns, ensuring safe and clean water for communities.

Key water quality characteristics that are crucial for assessing the acceptability of drinking water are included in the table. Standard water quality recommendations specify the limits for these factors, which include temperature, turbidity, and pH. Drinking water should have a pH between 6.5 and 8.5 to avoid being overly acidic or alkaline, since these extremes can cause corrosion in distribution systems and health risks. To preserve clarity and stop microbiological development, turbidity, which is measured in NTU (Nephelometric Turbidity Units), must be below 5 NTU. Water safety can be decreased by high turbidity, which can jeopardize disinfection procedures. Furthermore, the water's temperature range of 10°C to 30°C promotes palatability and lowers the possibility of dangerous microbes growing, guaranteeing that the water is still fit for human consumption.

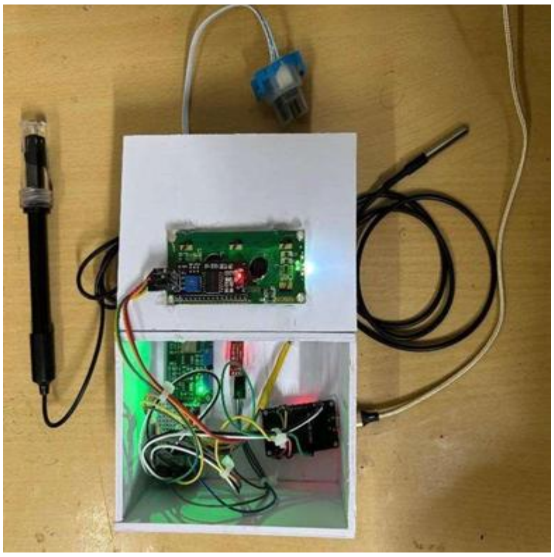
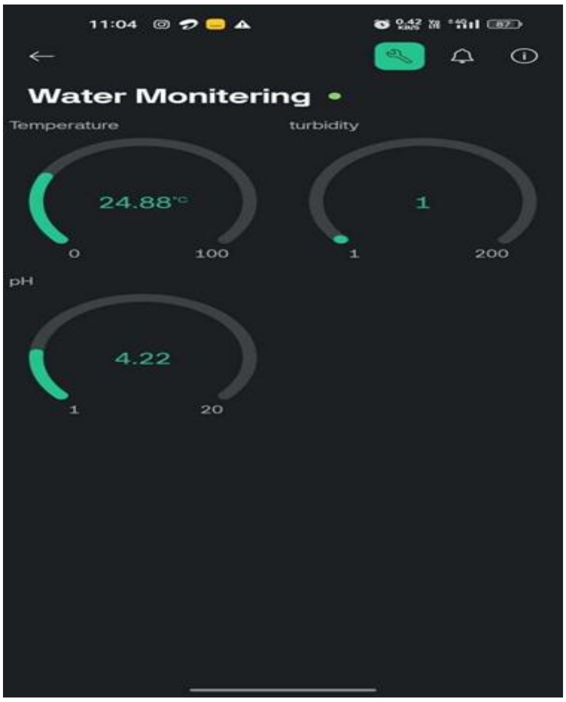


Figure 4. Water Quality Monitoring System Prototype



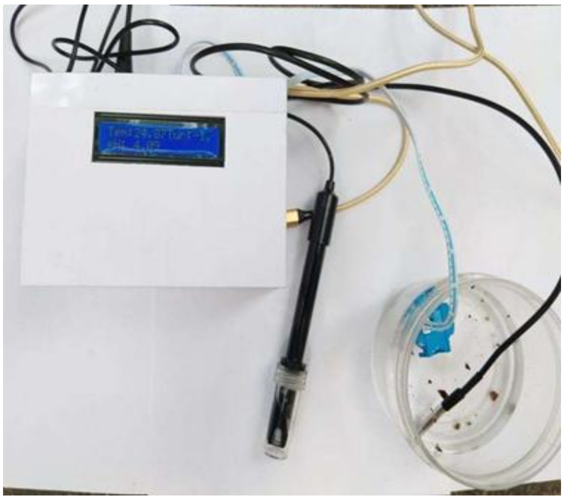


Figure 5. Water Quality Monitoring System (Acidic Sample)

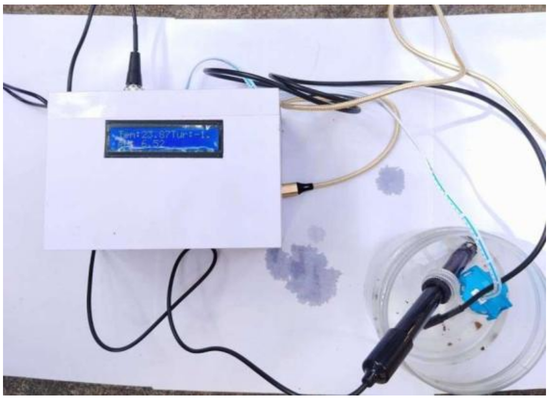
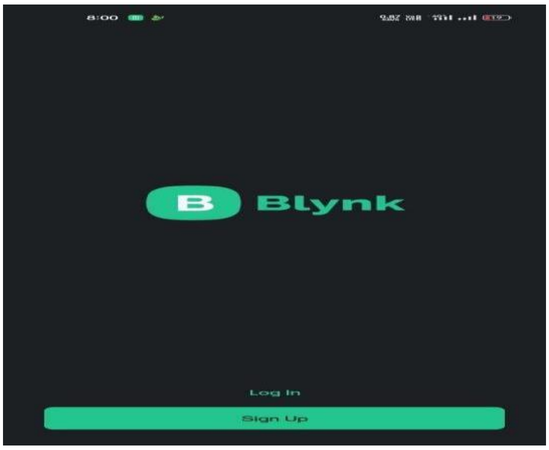
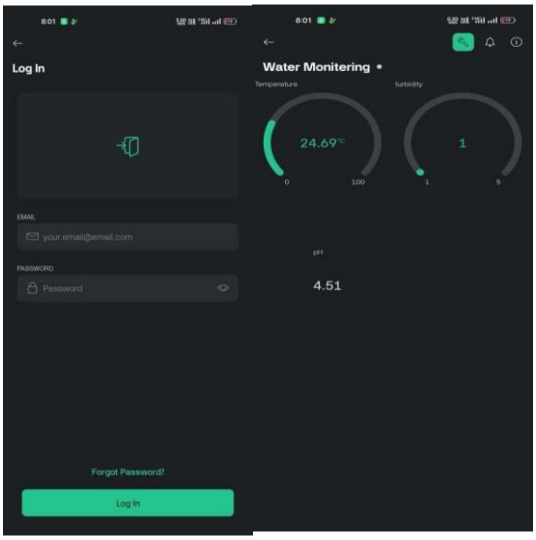


Figure 6. Water Quality Monitoring System (Neutral Sample)

With the help of sophisticated sensors and Internet of Things technology, these metrics may be continually monitored in the context of your IoT-based water quality monitoring system. To provide real-time data to a cloud-based platform, the system can use temperature, turbidity, and pH sensors that are integrated with microcontrollers and communication modules.



Welcome Screen



Monitoring Screen

Figure 7. Dashboard of Blink App

This technology guarantees prompt identification of violations from acceptable water quality criteria by automating the monitoring process. To inform users or authorities of any changes that can point to contamination or system malfunctions, alerts can be created. By facilitating early interventions and data-driven decision-making, such proactive monitoring improves water management techniques, protects public health, and promotes sustainable resource consumption. The developed model is tested with three different water samples and the results are tabulated in Table 2

Table.1 Drinking Water quality parameter range

Parameter	Range
PH	6.5 to 8.5
Turbidity	< 5 NTU
Temperature	10 to 30^0 C

Table 2. Water quality parameters for different samples.

Sample	Parameter	Measured Value
Water Sample 1	pH	7.5
	Turbidity	1 NTU
	Temperature	20° C
Water Sample 2	pH	9.3
	Turbidity	5 NTU
	Temperature	29.4° C
Water Sample 3	pH	4.1
	Turbidity	4 NTU
	Temperature	26.4° C

From the analysis, water sample 1 is drinkable and other two samples are not drinkable. The table compares the pH, turbidity, and temperature of three distinct water samples in order to determine whether or not they are fit for human consumption. Water Sample 1's temperature of 20°C, pH of 7.5, and turbidity of 1 NTU are all within permissible limits for drinking water. Because it satisfies the necessary requirements specified in water quality rules, this sample is considered drinkable. On the other hand, Water Sample 2 exhibits turbidity of 5 NTU at the highest permitted threshold and a pH of 9.3, which is higher than the permissible top limit of 8.5. Its temperature of 29.4°C is within acceptable bounds but on the upper end of the spectrum. This sample is unsafe to consume because of its high pH.

Likewise, Water Sample 3 has excessive acidity with a pH of 4.1, which is well below the permissible range of 6.5 to 8.5. Its low pH makes it unfit for human consumption, even if its turbidity of 4 NTU and temperature of 26.4°C are within acceptable bounds. This research highlights how crucial it is to concurrently monitor several water quality metrics in order to guarantee safety. Water monitoring systems that use Internet of Things (IoT)-based sensors would enable real-time tracking and early identification of such abnormalities, supporting efficient management and guaranteeing availability to clean drinking water.

CONCLUSION

Monitoring of Turbidity, PH & Temperature of Water makes use of water detection sensor with unique advantage and existing GSM network. The system can monitor water quality automatically, and it is low in cost and does not require people on duty. So the water quality testing is likely to be more economical, convenient and fast. The system has good flexibility. Only by replacing the corresponding sensors and changing the relevant software programs, this system can be used to monitor other water quality parameters. The operation is simple. The system can be expanded to monitor hydrologic, air pollution, industrial and agricultural production and so on. It has widespread application and extension value. By keeping the embedded devices in the environment for monitoring enables self protection (i.e., smart environment) to the environment. To implement this need to deploy the sensor devices in the environment for collecting the data and analysis. By deploying sensor devices in the environment, we can bring the environment into real life i.e. it can interact with other objects through the network. Then the collected data and analysis results will be available to the end user through the Wi-Fi.

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