Real-Time Water Quality Monitoring System using the Arduino Uno and a Nextion Touchscreen

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***Abstract*—Water Quality Monitoring Systems (WQMS) are essential for safeguarding public health and ensuring environmental sustainability by maintaining the safety and usability of water resources. Effective monitoring requires timely data collection to detect contamination and environmental risks. This study developed an Arduino-based WQMS that integrates multiple sensors to measure key parameters, including the potential of Hydrogen (*pH*), Total Dissolved Solids (*TDS*), turbidity, and environmental temperature, using a multi-sensor fusion approach for comprehensive real-time monitoring. The system features a Nextion touchscreen interface that not only displays real-time data but also provides interactive user feedback. A dynamic visual alert mechanism changes the background to red when sensor readings exceed predefined safety thresholds, immediately notifying users of potential risks. To evaluate the performance of the WQMS, experiments were conducted using three distinct media (Tap water, milk, and saltwater) under various conditions (e.g., different temperatures, turbidity levels, and dissolved solid concentrations). The results demonstrated the reliability of the WQMS in detecting variations in water quality parameters and providing real-time, user-friendly feedback through the touchscreen interface. The system successfully enhanced data visualization, accessibility, and monitoring simplicity, making it an affordable and adaptable solution for household, agricultural, and industrial applications.**

***Index Terms*—Water Quality Monitoring, Nextion Touchscreen, Real-Time Feedback, Arduino, Dynamic Alerts**

I. Introduction

Water quality is a critical factor influencing human health, environmental sustainability, and industrial processes. As the most abundant resource on Earth, covering over 75 percent of the surface of plant [1], water is essential for sustaining life and supporting various sectors, including domestic use, agriculture and industrial operations [2]. However, freshwater resources are increasingly contaminated due to human activities, threatening their safety and usability. Rapid growth in the global population and urbanization has contributed significantly to the deterioration of freshwater resources [3]. Pollution from industrial waste, household wastewater, vehicle emissions, and agricultural runoff introduces harmful chemicals and excess nutrients into water bodies. The sources of pollution degrade water quality, posing serious risks to human health and ecosystems. Contaminated water can cause waterborne diseases, harm aquatic life, and disrupt industrial processes that rely on clean water [4]. These challenges highlight the urgent need for effective monitoring and management to prevent adverse health and environmental impacts [5].

Assessing water quality is complex due to the multiple factors that influence it. The chemical and physical properties of water vary depending on its intended use, requiring different quality standards for different purposes [6]. For example, drinking water must meet strict safety regulations to protect human health, while water used in agriculture or industry must meet specific quality parameters to ensure efficiency. Contaminants such as heavy metals, organic pollutants, and microorganisms must be continuously monitored to prevent health risks and ensure compliance with regulations [7]. Traditional water quality monitoring methods, often involving laboratory analysis, can be time-consuming, expensive, and require specialized expertise. Additionally, many real-time monitoring solutions are either too costly or not widely accessible, making them impractical for widespread use, especially in resource-limited settings. These limitations underscore the need for an affordable, accessible, and user-friendly monitoring system that can provide real-time data to enable timely interventions and mitigate risks.

To address these challenges, this study proposes the development of an integrated Water Quality Monitoring System (WQMS) that provides real-time assessment of multiple parameters. The primary research question guiding this study is: How can an affordable and accessible WQMS be designed to effectively monitor key water quality indicators in real-time while ensuring usability and reliability? The proposed WQMS is based on an Arduino Uno microcontroller and employs a combination of sensors to measure potential of Hydrogen (*pH*), turbidity, Total Dissolved Solids (*TDS*), and temperature with high precision. It features a Nextion touchscreen interface for real-time data visualization and dynamic feedback, providing immediate alerts when water quality parameters exceed predefined safety thresholds. Unlike conventional systems that require technical expertise, the proposed solution is designed to be user-friendly, ensuring accessibility for a wide range of users. Its modular and scalable architecture allows for adaptation across multiple applications, including household water monitoring, industrial water management, and environmental studies.

The primary contributions of this research are as follows: it integrates multiple water quality parameters into a single platform, improving efficiency and reliability; it introduces a user-friendly interface with dynamic visual alerts, simplifying data interpretation and enabling prompt decision-making; and it demonstrates adaptability to different environments through performance evaluation across various liquid types, including tap water, saltwater, and milk. This study advances existing WQMS by enhancing real-time environmental assessment and expanding their practical applications. This study is structured as follows: Section 2 presents related studies. Section 3 outlines the methodology. Section 4 discusses the results. Section 5 concludes the study by summarizing key findings, discussing contributions, and proposing future work to enhance the capabilities of the WQMS and expand its applications.The main abbreviations used throughout this paper are summarized in Table I for clarity and reference.

II. Related Studies

The use of Internet of Things (IoT) technologies in water quality monitoring has been a key focus in recent research. Munara *et al.* [8] developed a flexible system that monitors *pH*, turbidity, and temperature, sending data wirelessly to a cloud-based storage system for real-time analysis. Similarly, Correa *et al.* [9] created a system using edge processing and an IoT gateway to transmit measurements to a centralized database. Budiarti *et al.* [10] developed an IoT platform with active and passive sensors communicating through the Message Queuing Telemetry Transport (MQTT) protocol for real-time data sharing. While these IoT-enabled systems improved functionality by enabling remote monitoring, they depend heavily on constant internet access and cloud infrastructure, which increases costs and limits applicability in offline or remote areas. The proposed WQMS addresses these issues by using a Nextion touchscreen interface to provide real-time, local feedback without requiring internet connectivity, simplifying deployment and reducing costs. Other studies have investigated Arduino-based multi-parameter water quality monitoring as a low-cost solution. Araneta and Arvin *et al.* [11] developed a system capable of measuring *pH*, TDS, and temperature in real-time, demonstrating the feasibility of microcontroller-based water assessment. However, their system relied on serial output to a computer for data visualization and lacked an integrated local interface, limiting usability in standalone or non-technical environments. Alam *et al.* [12] also presented an Arduino-based platform measuring *pH*, temperature, and dissolved oxygen, using simple LCDs for data display and basic data logging. However, these systems lacked dynamic, interactive feedback or threshold-based alerts, which can be critical for non-specialist users to identify unsafe water conditions.

Previous research on user interfaces for water monitoring revealed further limitations. Huang *et al.* [13] and Huang and Xie [14] designed microcontroller-based water dispensers displaying water temperature on basic LCD screens. However, these systems focused solely on single-parameter measurement, temperature, without assessing other water quality parameters such as *pH*, TDS, or turbidity. Munara *et al.* [8] also used LCDs for real-time sensor data visualization but lacked features like threshold-based alarms or intuitive cues to assist non-technical users in interpreting measurements. The proposed WQMS bridges these gaps by integrating multiple sensors, measuring *pH*, TDS, turbidity, and temperature, into a single system with a Nextion touchscreen interface. This design enables clear, real-time visualization and dynamic visual alerts when any parameter exceeds predefined safety thresholds, offering a practical balance between functionality and simplicity. Its flexible, standalone architecture allows it to be used in a variety of applications, including household water testing, industrial processes, and environmental monitoring, while avoiding dependence on external devices or cloud connectivity. The proposed system thus offers an affordable and user-friendly tool for managing water quality, focusing on reliability, accessibility, and ease of use.

III. Methodology

A. The System Overview

This section explains the design, setup, and testing of the WQMS. The firmware was developed using the Arduino Integrated Development Environment (IDE) and the C++ programming language. A system block diagram shown in Figure 1 illustrates the sensor inputs, data processing by the CPU and user interaction via the Nextion display.

B. Hardware Configuration

1) Arduino Uno Microcontroller: The Arduino Uno microcontroller collects data from the analogue sensors (A0–A5), processes it against preset safety thresholds, and sends results to the Nextion touchscreen via UART communication. It also powers the sensors and display using its 5V and GND pins. Arduino was chosen for its simplicity, low cost, and easy

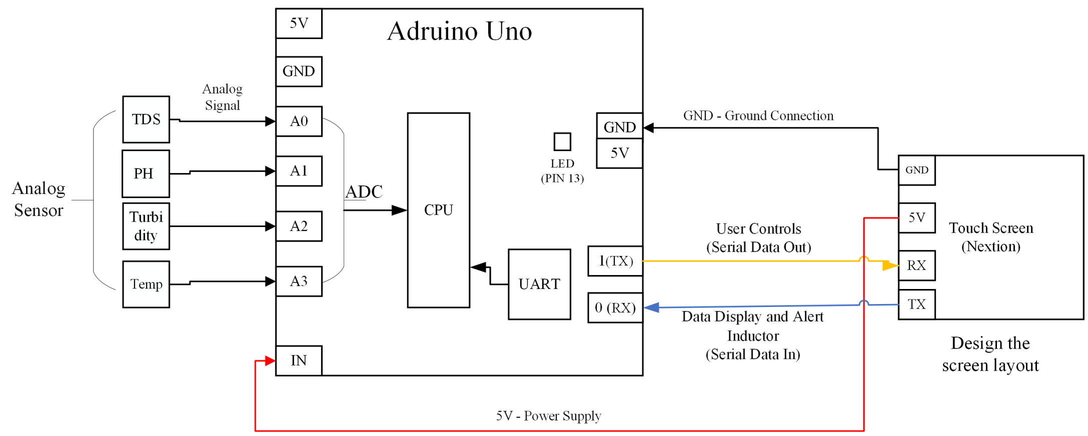

Figure 1: High-Level Diagram of the Proposed Water Monitoring System.

TABLE I: Abbreviations and Nomenclature

Abbreviations	Nomenclature	Abbreviations	Nomenclature
WQMS	Water Quality Monitoring System	MQTT	Message Queuing Telemetry Transport
pH	Potential of Hydrogen	IDE	Integrated Development Environment
TDS	Total Dissolved Solids	ppm	Parts per million
IoT	Internet of Things	NTU	Nephelometric Turbidity Unit
UART	Universal Asynchronous Receiver-Transmitter	TX/RX	Transmit / Receive Pin

integration with multiple sensors and the touchscreen. Unlike more complex platforms like Raspberry Pi, Arduino offers sufficient performance for real-time monitoring with lower power consumption and straightforward development for non-technical users.

2) Nextion Touchscreen: The Nextion touchscreen served as the user interface of the system, displaying water quality data in real-time. It communicated with the Arduino Uno through UART, with its TX and RX pins connected to the Arduino's RX and TX pins. The touchscreen got its power from the 5V and GND pins of the Arduino. It gave users visual feedback by dynamically changing its background color.

3) Sensors: Each sensor measures a specific water quality parameter and outputs an analogue voltage that reflects the measured value. The *pH* sensor identified whether the water was acidic or alkaline. The *TDS* sensor evaluated the amount of dissolved solids to determine water purity. The turbidity sensor measured water clarity by analysing how light scatters in the water. The LM35 temperature sensor recorded the environmental temperature. The Arduino Uno processes data and displays real-time values on the Nextion touchscreen, ensuring detailed monitoring. Table II provided the specifications for each sensor used in the system. It summarized the sensor specifications, highlighting their measurement ranges, accuracies, signal outputs, and connections to the Arduino Uno.

C. Software Implementation

1) Arduino Integrated Development Environment: The Arduino IDE was used to program the Arduino Uno microcontroller, which collects data from the sensors. The *analogRead()* function converted the analogue signals of the sensors into digital values. These values were processed using smoothing algorithms to minimize noise and improve accuracy. The microcontroller compared the processed data with predefined safety thresholds to check for any issues. To manage timing without blocking other tasks, the *millis()* function was used. This allows the system to collect data and provide feedback at the same time. The processed data was sent to the touchscreen. Could easily update to an Arduino Uno R4 WIFi to provide Internet connectivity and hence IoT functionality.

2) Nextion Editor: The Nextion Editor was used to design the touchscreen's graphical interface, enabling user-friendly interaction and real-time updates. Its drag-and-drop features allowed for the creation and customization of elements like *buttons*, *text fields*, *progress bars*, *sliders*, and *hotspots*, organized into purpose-specific screens. For example, the Parameter screen displayed live sensor readings, the Standard screen outlined water quality thresholds, and the Tips screen provided helpful advice. Dynamic feedback was implemented using commands like *setText()* to update text fields, *setValue()* to adjust progress bars for turbidity or *TDS* levels, and *setPHPageBackgroundColor()* to change the background colour based on safety limits. *Hotspot* elements simplified navigation, allowing users to return to the main menu or view details with a single touch. Once designed, the interface was compiled into a *.tft* file and uploaded to the touchscreen via an SD card, ensuring seamless integration with the Arduino Uno and the system.

TABLE II: Specifications of Sensors Used in the Proposed Water Quality Monitoring System

Sensor	Measuring Range	Accuracy	Analog Signal Output	Connected Pin
pH Sensor	0–14 *pH*	±0.1 *pH* (25°C)	0–5 V	A1
TDS Sensor	0–1000 ppm	±10% F.S. (25°C)	0–2.3 V	A2
Turbidity Sensor	0–1000 NTU	±5 NTU	0–4.5 V	A3
LM35 Temperature	-55°C to +150°C	±1°C	10 mV/°C	A4

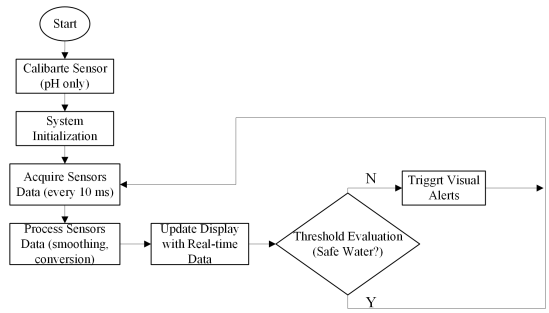

Figure 2: System Design Diagram of the Proposed Water Monitoring System.

D. System Design

The WQMS was illustrated in Figure 2, highlighting its sequential workflow. The flowchart delineates key processes, including calibration, data acquisition, processing, threshold evaluation, and user feedback. The *pH* sensor was calibrated using three standard buffer solutions (*pH* 7.00, *pH* 4.00, and *pH* 10.00) to ensure accurate readings. This process established the sensor's slope and offset by adjusting its output to match the known values of the solutions. Calibration for *TDS* and turbidity sensors was not performed due to time constraints, making their readings indicative rather than precise. Temperature compensation was also omitted, as the focus was on ensuring reliable *pH* measurements, which were critical for water quality assessment.

1) System Initialization: The system initialized by configuring the Arduino Uno for serial communication, setting up input/output pins to connect sensors and the touchscreen, and starting the main loop for continuous data collection and processing

2) Acquire Sensor Data: The Arduino collected analog signals from the sensors at a fixed interval of 10 milliseconds, allowing for timely and consistent data updates. Each voltage output corresponded to a specific water quality parameter, ensuring accurate processing.

3) Process Sensor Data: The raw sensor data was processed to remove noise and improve accuracy. A smoothing algorithm stabilized readings by averaging multiple measurements over a set time interval, minimizing fluctuations caused by environmental noise or interference. For the *TDS* sensor, a median filter sorted readings and selected the middle value, effectively eliminating extreme outliers while maintaining data reliability. Table III summarizes the comparison between smoothing techniques: the Simple Moving Average was ideal for general noise reduction due to its simplicity and speed but struggled with rapid changes, while the Median Filter excelled at handling outliers and sharp transitions, albeit with slower response times and higher computational demands. These methods ensured stable and reliable outputs.

The system converted raw analog sensor data into meaningful values using specific formulas. Raw analog values (0–1023) were first scaled to voltages (0–5V), which were then used for parameter-specific calculations. The *pH* sensor used calibration formulas to convert voltage into *pH* values, while the *TDS* sensor applied a temperature-compensated formula to calculate dissolved solid concentrations in parts per million (ppm). The turbidity sensor utilized a quadratic equation to determine Nephelometric Turbidity Unit (NTU) levels, and the temperature sensor converted voltage into Celsius using a linear equation. Table IV outlines the conversion tasks, descriptions, and formulas, ensuring reliable data processing for effective water quality monitoring.

4) Threshold evaluation: Threshold evaluation was essential for assessing water quality. Processed sensor values were compared against predefined safety limits. If all values remained within safe ranges, monitoring continued; if any parameter exceeded its limit, a visual alert was triggered to notify the user promptly. The Nextion touchscreen displayed real-time sensor values, enabling continuous monitoring. When thresholds were breached, dynamic visual alerts, such as a red background for unsafe conditions, provided immediate warnings. This feedback mechanism enhanced user awareness, simplified decision-making, and ensured effective system usability.

5) Loop: The system continuously loops to collect new sensor data, enabling real-time water quality monitoring after displaying results and alerts.

IV. RESULTS AND DISCUSS

The *pH* data demonstrated the reliability of the WQMS in measuring water quality. For Tap water, it recorded a stable *pH*

TABLE III: Comparison of Smoothing Noise Techniques

Technique	Best For	Strengths
Simple Moving Average	General noise reduction	Fast, simple, and smooths moderate noise
Median Filtering	Data with outliers or sharp transitions	Filters extreme anomalies effectively

TABLE IV: Summary of Sensor-to-Voltage Conversion Tasks and Descriptions

Task	Description	Example Formula
Voltage Conversion	Converts raw analogue values (0–1023) to voltage (0–5V).	$Voltage\ (V) = \frac{Analog\ Value \times 5}{1023}$
pH Calculation	Converts voltage to *pH* based on calibration.	$pH = 2.105 \times (Voltage + 1.5954)$
TDS Calculation	Accounts for temperature compensation and calculates *TDS* in ppm.	$TDS\ (ppm) = (133.42 \times cV^3 - 255.86 \times cV^2 + 857.39 \times cV) \times 0.5$
Turbidity Calculation	Determines turbidity in NTU using a quadratic equation.	$Turbidity\ (NTU) = -2.801 \times V^2 + 14.32 \times V - 10.85$
Temperature	Converts sensor output voltage into degrees Celsius.	$Temperature\ (°C) = Voltage \times 100$

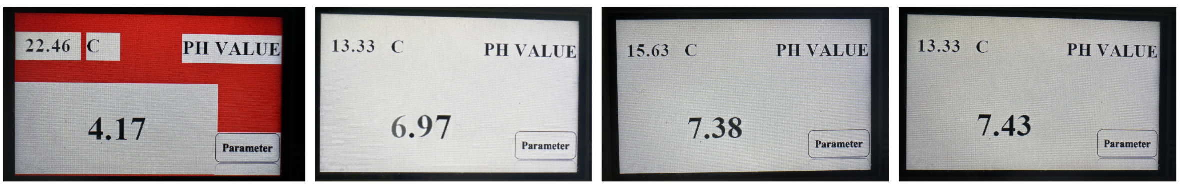

Figure 3: *pH* Value Display on the Nextion Touch Screen

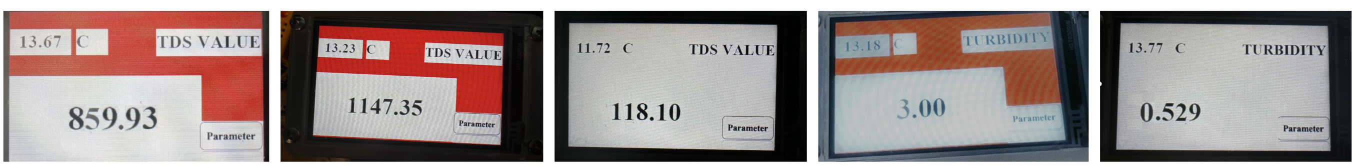

Figure 4: *TDS* and Turbidity Value Display on the Nextion Touch Screen

of 7.43 (neutral); for saltwater, a slightly higher *pH* of 7.38 (due to alkaline salts); and for milk, a *pH* of 6.97 (slightly acidic due to lactic acid). These results aligned with expected values and were displayed in Figure 3. Notably, the measured *pH* values for milk and water were slightly higher than the standard reference values provided by Lenntech [15], which state pure water has a *pH* of 7.0 and milk a *pH* of 6.6. This discrepancy could stem from sample composition, calibration methods, or environmental factors. For instance, the *pH* value of milk might have been influenced by processing or storage, and the calibration process, while effective, may not match laboratory-grade precision. Despite these variations, the *pH* sensor delivered accurate and reliable readings suitable for real-world applications. Measuring *pH* is crucial for assessing water safety and detecting quality changes. The ability of the WQMS to measure *pH* across different liquids highlights its versatility and reliability. By displaying real-time *pH* values on the touchscreen, it enables users to quickly evaluate water quality and make informed decisions.

The *TDS* measurements demonstrated the system ability of the WQMS to differentiate liquids with varying dissolved solids. Tap water showed a consistently low *TDS* value of 118.10 ppm, reflecting its purity. Saltwater exhibited a significantly higher *TDS* value of 1147.35 ppm due to its high salt content, while milk recorded a *TDS* value of 859.93 ppm, attributed to organic compounds and minerals. The Nextion touchscreen (Figure 4) provided real-time feedback, validating the sensitivity of the WQMS and responsiveness. The sharp *TDS* increase for saltwater and stable trends for milk and Tap water highlighted the reliability of the WQMS for real-time water quality monitoring across diverse applications.

The turbidity data highlights the precision of the WQMS in detecting water clarity across liquids. Milk showed a turbidity value of 3.00 NTU, reflecting its high turbidity due to fat and protein content, while saltwater and Tap water displayed low values of 0.529 NTU, indicating clarity. These readings, shown on the Nextion display (Figure 4), demonstrate the ability of the WQMS to capture variations. Although the similar turbidity values for saltwater and Tap water may raise questions, their low readings align with their clear nature. This functionality strengthens the applicability of the WQMS for domestic water monitoring and environmental assessments, where turbidity is a key water quality indicator.

The environmental temperature data reflects the consistency of the WQMS in monitoring temperature across liquid samples, with stable readings and minimal fluctuations for Tap water, saltwater, and milk. The real-time temperature display on the Nextion touchscreen's top-left corner (Figure 4) enhances user interaction and situational awareness, ensuring users are informed of environmental conditions while monitoring other parameters.

The Nextion touchscreen offers an intuitive interface, dynamically updating measurements and using background colour changes (red for alerts, white for normal) to signal deviations from safety thresholds. *pH* measurements stabilize within a defined range (6.5–8.5), *TDS* readings effectively differentiate water types (threshold: 500 ppm), turbidity monitoring triggers alerts above 1 NTU, and temperature readings remain consistent across liquid types. The pH sensor was calibrated using standard buffer solutions (pH 4.00, 7.00, and 10.00), achieving measurements within ±0.15 pH units of reference values. The TDS, turbidity, and temperature sensors provided consistent results for differentiating sample types, although future calibration with standard references will further enhance measurement accuracy. These findings confirm that the WQMS delivers practical, multi-parameter water quality assessments suitable for a wide range of applications.

V. Conclusions

This study successfully developed a WQMS using an Arduino platform and multiple sensors. While not all goals were fully achieved within the timeline, the system demonstrated its ability to provide reliable, real-time data for evaluating water quality. It measured key parameters, including potential of Hydrogen (*pH*), turbidity, Total Dissolved Solids (*TDS*), and environmental temperature, across different water types. The *pH* sensor delivered precise and consistent readings, crucial for monitoring acidity or alkalinity changes. The *TDS* sensor effectively distinguished between water types, detecting low dissolved solids in freshwater and higher concentrations in saltwater. However, the turbidity sensor showed limited sensitivity to particle variations, highlighting the need for future improvements to detect smaller particles and broaden its applications. The Nextion touchscreen interface enhanced usability by displaying real-time data clearly, enabling users to interpret water quality conditions without technical expertise. Its intuitive design and live updates make the system practical for diverse applications, from environmental monitoring to domestic and industrial water quality assurance.

Several opportunities for improvement and expansion have emerged. Regular calibration of *TDS* and turbidity sensors, ideally automated, will enhance accuracy and reduce manual effort. Integrating temperature and volume control mechanisms will stabilize readings and improve measurement reliability. Adopting cloud-based data collection will enable extensive storage and detailed analysis, supporting remote monitoring. Implementing IoT technology will facilitate real-time analytics and remote updates, making the system more dynamic. Advanced techniques like machine learning could identify patterns and predict issues, enabling proactive water quality management. Improving user interaction through intuitive interfaces and mobile notifications will broaden accessibility for non-technical users. These enhancements aim to strengthen the technical performance of the WQMS and expand its impact on environmental monitoring, regulatory compliance, and community health, making it more versatile and robust in addressing water quality challenges.

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