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Design and Implementation of an IoT-based Water Level and Quality Monitoring System for Mechatronics Applications

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ABSTRACT

Hands-on learning tools that integrate Internet of Things (IoT) technology remain limited in vocational aviation education, often restricting students to theoretical instruction without sufficient practical exposure. To address this gap, this study presents the design and development of an IoT-based water-level and quality-monitoring system as an interactive learning medium for the Mechatronics course at the Makassar Aviation Polytechnic. The system integrates three key sensors: an HC-SR04 ultrasonic sensor for water level measurement, a pH-4502C sensor for acidity detection, and a TDS sensor for dissolved solids analysis. Data from all sensors was processed by a NodeMCU ESP32 microcontroller, displayed locally on a 20×4 LCD, and transmitted in real time to the Thinger.io platform via Wi-Fi, enabling both local and remote monitoring. **The research** followed a Research and Development (R&D) methodology using a waterfall model, encompassing needs analysis, design, implementation, testing, and maintenance. Validation was conducted by comparing the instrument with standard instruments under identical conditions. Results showed average error rates of 4.38% for the ultrasonic sensor, 4.69% for the pH sensor, and 1.76% for the TDS sensor, indicating high measurement accuracy. **The findings demonstrate** that the developed system not only offers a reliable solution for real-time water monitoring but also functions as an effective pedagogical tool, strengthening students' competencies in sensor integration, microcontroller programming, and IoT-based communication. By bridging the gap between theory and practice, the system enhances student preparedness for Industry 4.0 and supports the advancement of technology-driven aviation education

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INTRODUCTION

The development of technology in the digital era has brought significant changes across sectors, including education and aviation. One key innovation is the Internet of Things (IoT), which enables devices to connect and exchange data automatically over the internet (Selay et al., 2022). In industry, IoT has been deployed across numerous monitoring systems to enhance operational efficiency, accuracy, and responsiveness (Dharmawan et al., 2022). Its adoption has demonstrated measurable impacts on operational safety, data reliability, and resource optimization, particularly when integrated with real-time monitoring platforms (Obaideen et al., 2022).

In vocational education, the use of IoT as a learning medium for mechatronics remains limited. At Politeknik Penerbangan Makassar, the learning media for the Mechatronics course remain suboptimal, with students often relying on theoretical instruction rather than sufficient hands-on practice (Bayu Purbo Wartoyo & Sarifuddin, 2023). Previous studies have highlighted the value of IoT-based learning environments in enhancing student engagement, technical skills, and problem-solving abilities (Badshah et al., 2024; Yilmaz & Karaoglan Yilmaz, 2023). Similarly, Learning Factories 4.0 have proven effective in developing practical competencies aligned with Industry 4.0 demands (Roll & Ifenthaler, 2021).

In water management, IoT-based monitoring has become increasingly important for ensuring both operational and environmental safety. Within the aviation industry, water monitoring systems play a crucial role in supporting aircraft operations, airport facilities, and safety mechanisms (Al Tahtawi, 2018). Several recent studies have demonstrated the feasibility and accuracy of IoT-based water quality systems. For example, Jabir et al. (2024) developed an ESP32-based monitoring system for drinking water depots using pH, TDS, and ultrasonic sensors, integrated with Telegram notifications. Rusdi and Supardi (2023) designed a similar system for aquariums, achieving high accuracy in measuring pH, TDS, and temperature. Likewise, Satrianata et al. (2023) implemented ESP32 with TDS monitoring for natural water filtration, while Zafi et al. (2024) proposed a TDS-based IoT system for aquaculture ponds. These studies confirm the growing relevance of ESP32 microcontrollers, which offer integrated Wi-Fi, low power consumption, and support for multi-sensor data processing.

Despite these advancements, most existing systems are designed for industrial or environmental applications, with limited emphasis on their educational role. Moreover, many prototypes focus on either water-level or water-quality parameters, but rarely both within an integrated framework (Saputra, 2020; Adityas et al., 2021). At Politeknik Penerbangan Makassar, no learning media currently enable cadets to directly engage with IoT-based water-monitoring systems, creating a gap in their readiness for technology-driven industry roles.

In light of this gap, the present study aims to design and develop an IoT-based water-level and quality-monitoring system as an interactive learning medium for the Mechatronics course at Politeknik Penerbangan Makassar. The proposed system integrates water-level, pH, and TDS measurements using a NodeMCU ESP32, with local data visualization via an LCD and remote monitoring via the Thinger.io platform. The objectives of this research are twofold: (1) to create an IoT-based learning tool for water monitoring and (2) to evaluate its feasibility through expert validation and functional testing. The novelty lies in combining multiple water parameters into a single IoT-enabled educational tool, providing students with both technical skills and applied understanding of Industry 4.0 concepts.

METHOD

This research employed the Research and Development (R&D) method. According to Zakariah et al. (2020, Research and Development (R&D) refers to the processes or steps undertaken to develop new products or to improve existing ones. This concept involves a series of research methods used to create a specific product and to evaluate its effectiveness. R&D plays a crucial role in innovation, enabling the creation of new technologies, products, services, or systems that can be utilized or marketed to increase a company's profit. The R&D method is a systematic research process aimed at developing new products or improving existing ones. This method includes stages such as needs assessment, product design, development, and evaluation (Boeing et al., 2022). (Tou et al., 2019) explains that the R&D method is used to develop new products or improve existing products through a systematic process, including needs identification, design, testing, and evaluation.

In developing the IoT-Based Water Level and Quality Monitoring System as a learning medium for Mechatronics at Politeknik Penerbangan Makassar, the Waterfall model was employed. The Waterfall Model is a linear and structured software development model. In this model, each stage of the software development process is carried out sequentially, beginning with requirements analysis, design, implementation, testing, and finally maintenance. This process requires that each phase be completed before proceeding to the next, thereby minimizing unplanned revisions later. The Waterfall Model is particularly suitable for projects with welldefined and stable requirements throughout the development process (Jordhy Sachsono, Rendani A H Hutagaol, Pikki Putra, 2025).

There are five stages in the waterfall method. The first stage is requirements analysis, which involves understanding and documenting the needs for the design, including both hardware and software components. A thorough requirements analysis helps define system specifications and ensures that all critical functionalities are considered before development begins. The second stage is design, in which the author develops detailed device designs, identifies the hardware components involved in the research, and specifies the system architecture to guide the development process. Design activities include selecting appropriate sensors, microcontrollers, communication modules, and planning software architecture for data acquisition and processing. The third stage is implementation, during which the device is built by designing hardware circuits and writing software. Development proceeds incrementally, with small modules or units coded and tested individually, a process known as unit testing. This approach enables early fault detection and facilitates debugging, thereby improving the overall quality and reliability of the system (Denert, 2020). Next is verification, in which the device design undergoes rigorous testing to determine whether it meets predetermined feasibility criteria. Feasibility tests are conducted by experts who evaluate the device's functionality, accuracy, reliability, and suitability as a learning medium. This stage ensures that the developed prototype aligns with the research goals and meets user needs, particularly in educational contexts, where usability and pedagogical effectiveness are critical (Miller, 2021). The final stage is maintenance, in which the device is operated and maintained to ensure continuous functionality. Maintenance activities include fixing errors or bugs not detected during previous testing phases, updating software components if necessary, and ensuring that the hardware remains operational over time. This stage is essential for sustaining the prototype's usability in actual learning environments and for future improvements or adaptations (Venters et al., 2018).

The writer employed the waterfall research method because it has a clear structure and is easy to understand and manage. Its sequential nature aligns well with the project's objectives and resource constraints, enabling systematic progress tracking and quality assurance throughout the development cycle. In addition, this research employs the Arduino IDE to program the hardware, leveraging its user-friendly interface and extensive community support for efficient coding and debugging (Monk, 2019). The writer conducted an experimental study and used a simulation model during development to predict system behavior prior to full implementation. The final expected outcome of this research is a functional prototype that can serve as a practical learning medium for mechatronics students. The systematic R&D approach, combined with the Waterfall model, ensures that the development process is methodical and aligns with both academic and technical requirements.

Device Design

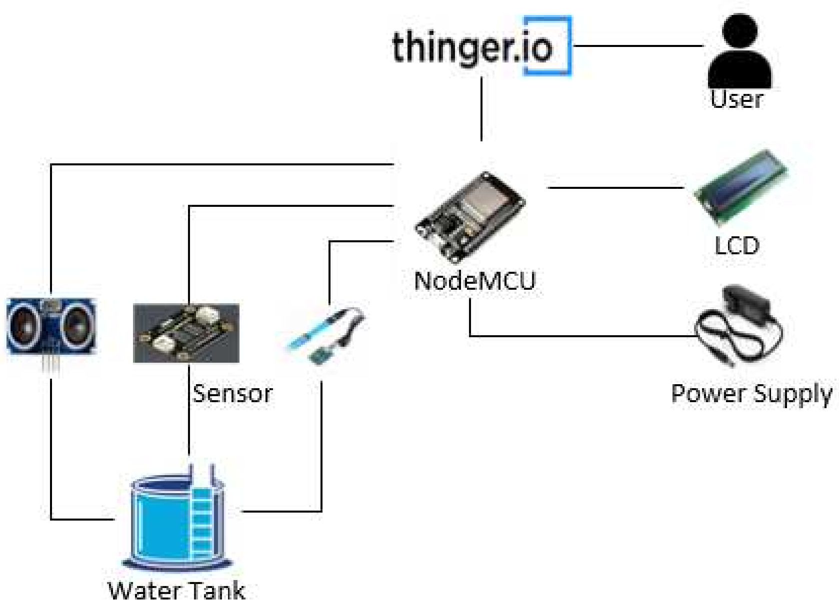

Figure 1. Device Design

The diagram illustrates the design of an IoT-based water-level and quality-monitoring system. This system integrates various components to collect, process, display, and transmit data in real time. At the core of the system is the NodeMCU ESP32, which functions as the main microcontroller. It is connected to several sensors, including an ultrasonic sensor for water-level detection and other analog sensors for measuring water-quality parameters such as pH and Total Dissolved Solids (TDS).

These sensors are placed in a water tank to gather real-time environmental data. The collected data is then processed by the NodeMCU and displayed on an LCD screen, allowing users to monitor the system locally. For remote monitoring, the system is connected to the Thinger.io platform via the internet. Through Thinger.io, users can access the data from anywhere, using a smartphone, computer, or any device with internet connectivity. The entire system is powered by a power supply, ensuring stable and continuous operation. With this configuration, the system serves not only as a functional environmental monitoring tool but also as an educational medium for students to learn about IoT, sensor integration, and microcontroller programming.

Device Components

The components of this IoT-based water-level and quality-monitoring device comprise both hardware and software, each playing a critical role in ensuring the system functions effectively and reliably. On the hardware side, the main components include several specialized sensors and modules. The HC-SR04 Ultrasonic Sensor is employed to accurately measure the water level by emitting ultrasonic waves and calculating the distance based on the time it takes for the echo to return. This non-contact method provides precise, real-time water-level measurements, which are essential for monitoring. To assess water acidity, the system uses the pH-4502C sensor, which measures pH and indicates water quality by indicating its acidity or alkalinity. In addition, a Total Dissolved Solids (TDS) Sensor is integrated to measure the concentration of dissolved solids, both organic and inorganic, in the water. Monitoring TDS levels is crucial for evaluating overall water purity and safety. To regulate the electrical power supply efficiently, the LM2596 Step-Down Module is incorporated, which reduces the DC input voltage to a stable and lower output voltage, thereby protecting sensitive components from voltage fluctuations. Furthermore, a buzzer is included as an alert system that sounds alarms or warnings when water parameters exceed predefined thresholds, ensuring prompt attention to critical conditions. Data visualization is facilitated by an LCD (Liquid Crystal Display), which displays relevant information, such as water level, pH, and TDS values, in legible characters and numbers for immediate observation. Finally, jumper wires are used extensively to connect all hardware components, providing flexible and reliable electrical pathways that complete the circuit.

On the software side, the system development relies on two primary tools. The Arduino Integrated Development Environment (IDE) serves as the programming platform for the microcontroller, enabling the creation, compilation, and uploading of firmware that controls sensor readings, data processing, and communication protocols. The Arduino IDE is favored for its simplicity, extensive library support, and large user community, all of which accelerate development and troubleshooting. Additionally, Thinger.io is used as an Internet of Things (IoT) platform to facilitate remote monitoring and control of the device. Through Thinger.io's cloud services, users can access real-time data and interact with the system via mobile or web applications, enhancing accessibility and flexibility. This integration enables users to receive alerts, view trends, and manage the system from any location, which is particularly valuable for educational purposes and operational monitoring in environments such as airports or industrial facilities. Together, these hardware and software components form a comprehensive ecosystem that supports accurate environmental sensing, effective data management, and user-friendly interaction, thereby fulfilling the research goals of creating an educational and functional IoT-based water monitoring system.

The process begins when the system is activated, triggering the sensors to measure water parameters such as water level, pH, and total dissolved solids (TDS). These sensors collect raw measurement data directly from the water source in real time. Once the measurements are taken, the microcontroller reads the sensor values and processes the data. At this stage, the system verifies whether the data has been successfully processed and is free from errors. If the processing is unsuccessful, the system returns to the measurement stage, ensuring accurate readings are obtained. When the data is successfully processed, the system displays the water parameter values locally on the LCD screen, allowing on-site users to view the current status immediately. Simultaneously, the processed data is transmitted to the Thinger.io IoT platform via an internet connection, enabling remote monitoring. On the Thinger.io dashboard, users can access real-time readings of water volume, pH, and TDS from anywhere with internet connectivity. This process ensures both local and remote visibility of water conditions, supporting timely decision-making and efficient monitoring. The cycle then repeats continuously, maintaining up-to-date tracking of water quality and level.

The testing technique used for the device is the comparison test method, also known as validation and accuracy testing. This method is carried out by comparing the measurement results from the IoT-based prototype with those from a standard digital measuring instrument that is reliable and widely used in the field. According to (Dawis et al., 2023), validation testing is essential to assess the accuracy level of a system against proven instruments, especially in the context of developing new technological devices. Therefore, each sensor in this device was tested and directly compared with a digital measuring tool as a benchmark.

Data Analysis Technique

The place of research was carried out at the Makassar Aviation Polytechnic. Data was taken from February to March, then preparation of devices and materials in April. Design and manufacture of device is carried out from May to June, device testing is carried out in July. The author employed a quantitative data analysis technique using an instrument in the form of a questionnaire. This questionnaire was distributed to two experts in the field, and each test was conducted by observing the readings from the IoT-based device and the comparison tool at the same time and under the same conditions. The measurement data were then used to calculate the deviation and expressed in the form of a percentage error, using the following formula:

$$\text{Percentage Error} = \left(\frac{|\text{Measured Value} - \text{True Value}|}{\text{True Value}} \right) \times 100\%$$

Figure 2. Percentage Error Formula

The feasibility categories based on the percentage error are as follows:

Table 1. Error Percentage Categories

Percentage Error	Category
≤ 5 %	Very Accurate
5,01 % - 10 %	Fairly Accurate
10,01 % - 15 %	Less Accurate
>15 %	Inaccurate

RESULTS AND DISCUSSION

The hardware configuration of the IoT-based water-level and quality monitoring system comprises five categories: control unit, sensors, power supply, communication, and alert mechanism. The ESP32 microcontroller functions as the central control unit, enabling not only data acquisition and processing but also integrated connectivity for real-time transmission. This integration illustrates the system's efficiency and scalability, distinguishing it from conventional microcontrollers such as the Arduino Uno, which require additional modules for IoT functionality.

The sensor suite comprises an ultrasonic sensor for water-level measurement, a PH-4502C sensor for pH detection, and a TDS sensor for dissolved solids concentration. By combining multiple parameters into a single framework, the system achieves a comprehensive monitoring capability that is both practical and pedagogically valuable. All sensor data is processed by the ESP32 and visualized on a 20×4 LCD via I2C, thereby reducing pin usage and wiring complexity. This design choice emphasizes resource optimization and streamlined hardware integration.

A 12V 2A adapter provides power regulation, stepping the voltage down through an LM2596 module to 5V, ensuring stable and reliable operation across all components. For the alert mechanism, a passive buzzer activates when parameters exceed predefined thresholds, offering immediate local warnings that enhance the system's responsiveness.

Analytically, the design demonstrates how sensor integration, efficient communication protocols, and robust power management converge to create a reliable, adaptive, and user-friendly monitoring platform. The reduced hardware complexity, combined with real-time data visualization, not only increases system reliability but also reinforces its effectiveness as an educational tool, bridging the gap between theoretical instruction and applied learning.

The following is a schematic of the device.

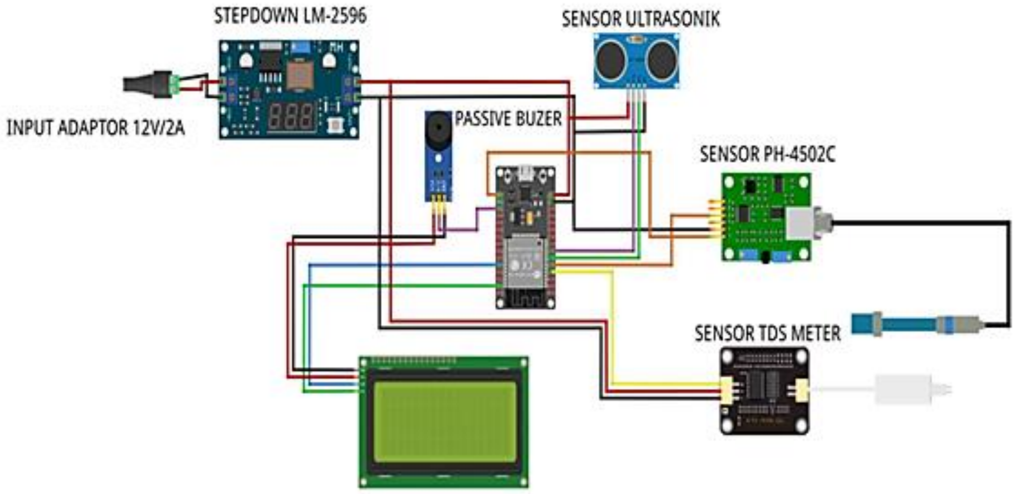

Figure 3. Device Circuit

The results of this design show that all key water parameters can be monitored simultaneously using a single integrated system—unlike previous implementations, which typically monitored only partial aspects of water quality or level.

Figure 4. Monitoring Display on the LCD

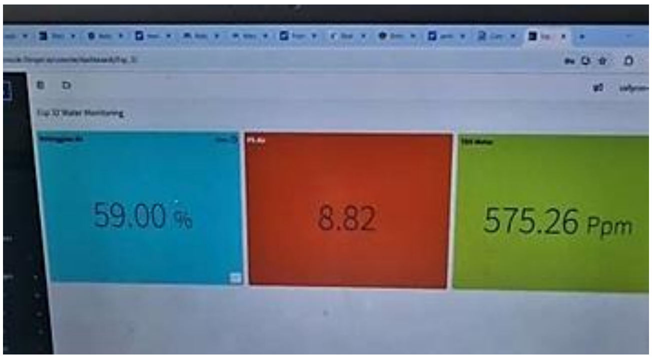

Figure 5. Monitoring Display on the Thinger.io

Figures 4 and 5 demonstrate that the system successfully presents the sensor data readings in a synchronized manner between the local display (LCD) and the online interface (Thinger.io).

Recent comparative studies have highlighted the advantages of the ESP32 over other microcontrollers in multi-sensor IoT applications. For instance, a study comparing ESP32 with Arduino UNO R3 in a multi-sensor environment (temperature, humidity, and flow rate) demonstrated that the ESP32 achieved higher accuracy, lower latency, and greater reliability, particularly when handling simultaneous sensor inputs. In contrast, Arduino UNO showed performance degradation under similar conditions (ResearchGate, 2024). Similarly, a comparative study of the Arduino UNO, Raspberry Pi 4, and ESP32 concluded that the ESP32 offers the best balance of processing power, integrated Wi-Fi connectivity, and peripheral support, making it well-suited for real-time IoT monitoring and educational applications (IJRASET, 2024). In terms of communication protocols, reviews emphasize that I2C offers simplicity, low power consumption, and efficient multi-peripheral integration, which makes it preferable for systems with multiple low-speed sensors. In contrast, SPI—although faster—requires more wiring and power, making it less optimal for resource-constrained IoT educational tools (Wevolver, 2023). Collectively, these findings support the study's design choices, underscoring the ESP32 and I2C communication as efficient, reliable, and scalable solutions for water-level and quality monitoring in a learning context.

Based on the test results, several notable weaknesses were observed in the Water Level and Quality Monitoring System. One of the primary issues concerns the Total Dissolved Solids (TDS) sensor, which exhibited a relatively slow response time in delivering parts per million (ppm) readings. This latency becomes particularly apparent when there are sudden changes in water conductivity, delaying the system's ability to reflect real-time fluctuations in water quality. Such delays could limit the system's effectiveness in environments where rapid detection of contamination or quality shifts is critical. Another identified drawback concerns the buzzer component used as an alert mechanism. The buzzer was found to have low sound intensity, which significantly reduces its effectiveness as a warning device. This limitation is especially problematic in noisy environments, where ambient noise can easily overpower the alarm signal, thereby reducing the likelihood of timely alerts and immediate responses from users or operators. Furthermore, the pH sensor showed occasional instability in its readings, manifesting as fluctuations even when the water conditions were otherwise stable and consistent. These measurement irregularities likely stem from suboptimal initial calibration of the sensor, which affects the consistency and precision of the pH data collected. Such fluctuations can introduce uncertainty in interpreting water acidity levels, potentially affecting the overall reliability of the monitoring system. Collectively, these weaknesses highlight important considerations for further refining the system's hardware components to improve performance and reliability in practical applications.

The IoT-based water-level and quality monitoring system designed in this study generally functions as intended. The sensors integrated with the microcontroller can detect water quality parameters and display them in real time via the LCD and the Thinger.io dashboard. However, based on the device testing results, several weaknesses were identified that should be addressed in subsequent development.

First, the TDS sensor exhibits a slow response in measuring the total dissolved solids (TDS) content of water, particularly when there is a sudden change in water quality. This condition causes delays in updating the data displayed on both the LCD screen and the IoT dashboard. According to (Sugiharto et al., 2023), the TDS sensor requires a sufficient stabilization period before providing accurate results, especially when there is a drastic shift in water conductivity levels. Second, the buzzer used as a warning indicator produces sound at relatively low intensity, making it difficult to hear when the device is placed in noisy environments. (Fachrun Nisa & Nurul Chafid, 2022) state that one of the causes of weak alarm sound is the use of a low-power buzzer, which is less suitable for field monitoring applications that require a high level of user responsiveness. Third, the pH sensor exhibits fluctuating readings even when the water conditions remain relatively stable, particularly when the device is first powered on. This is suspected to be due to the initial calibration process not being performed optimally. This phenomenon was also observed by Adityas et al. (, who explained that instability in pH readings can be caused by buffer calibration errors as well as the influence of water temperature on the sensor electrode. Therefore, a precise calibration procedure is required to obtain consistent results.

Operational Mechanism of the Water Level and Water Quality Monitoring System

This IoT-based water-level and water-quality monitoring system operates autonomously by integrating an ESP32 microcontroller with several key sensors: an HC-SR04 ultrasonic sensor for water-level measurement, a pH-4502C sensor for water acidity measurement, and a TDS sensor for measuring total dissolved solids (TDS) in the water. All sensor data is transmitted in real time to the Thinger.io platform and displayed locally on a 20x4 LCD.

The system's general workflow begins with initialization. When powered on, the ESP32 microcontroller automatically connects to a Wi-Fi network using a preprogrammed SSID and password stored in its memory. Following a successful network connection, the microcontroller initializes communication with all peripheral components, including sensors for water-level and quality measurements, the LCD for local data visualization, and the buzzer for alarm signaling. This initialization stage ensures that all hardware components are synchronized and ready for continuous operation. The next phase involves water-level monitoring, which is primarily performed using the HC-SR04 ultrasonic sensor. This sensor operates by emitting ultrasonic waves toward the water surface and measuring the time required for the echo to return. The time delay is then converted into a distance value expressed in centimeters, representing the height of the water column. Subsequently, this raw distance measurement is converted into a percentage indicating the relative water level in the tank. If the measured water level falls below a predefined threshold (20% or lower), the system activates the buzzer as an audible alarm, alerting users to a critically low water level that may require immediate attention.

Water quality monitoring is conducted through two key sensors, starting with the pH-4502C sensor for pH measurement. This sensor measures the analog voltage generated by the water sample, which correlates with the sample's acidity or alkalinity. The analog signal is converted into a pH value using a calibration formula established during system setup. This pH reading is then displayed on the device's LCD screen and simultaneously transmitted to the Thinger.io IoT platform for remote monitoring. The system further categorizes pH values by displaying status messages; for instance, if the pH is 7 or below, the status "Acidic" is displayed, whereas neutral or alkaline readings trigger corresponding status updates to inform users of the current water condition.

Complementing the pH sensor, the Total Dissolved Solids (TDS) sensor measures the concentration of dissolved solids in the water, expressed in parts per million (ppm). This measurement is derived from assessing the electrical conductivity of the water, which is influenced by the presence of both organic and inorganic dissolved substances. The sensor outputs an analog voltage, which undergoes compensation to improve accuracy before being converted into a quantitative TDS value. As with the pH data, TDS measurements are displayed on the local LCD and uploaded to the Thinger.io dashboard, enabling comprehensive water quality monitoring. Data transmission and display are essential to the system's functionality. All sensor data, including water level, pH, and TDS readings, are continuously sent to the Thinger.io cloud platform via the established internet connection. This enables users to access real-time monitoring data remotely via mobile devices or computers, facilitating observation and management from virtually any location. At the same time, the device provides immediate local feedback by displaying all relevant data on a 20x4-character LCD screen, ensuring that users in the field have direct access to up-to-date information without requiring internet access.

Finally, the system operates under a continuous monitoring paradigm. While powered and active, the microcontroller repeatedly acquires sensor readings at regular intervals, processes the data to derive meaningful metrics, and transmits the results to the cloud dashboard. This continuous loop enables ongoing surveillance of water conditions, allowing users to monitor parameters locally via the LCD or remotely via an internet connection. The system's design thus supports both immediate on-site decision-making and long-term remote management, thereby fulfilling the educational and practical objectives of the IoT-based water-level and quality-monitoring approach. The system operates in a continuous monitoring loop, repeatedly acquiring sensor data, processing measurements, and updating both local and remote interfaces. This real-time operational model supports both immediate situational awareness and long-term monitoring, aligning with the educational and practical objectives of IoT-based environmental monitoring systems. As demonstrated by (Rossydi et al., 2021; Nugrah et al., 2024) such architectures are particularly effective for applied engineering education, as they integrate sensor technology, data communication, and real-time decision support within a single functional framework.

Feasibility Test Result

On July 17, 2024, validation testing using a comparison method was conducted by two lecturers from the Makassar Aviation Polytechnic. This testing involved comparing sensor readings from an IoT prototype with those from standard measurement instruments under identical time and environmental conditions. The test results demonstrated that the system achieved high accuracy in approaching reference values and maintained consistent sensor reading reliability. This type of validation—comparing the output of a prototype device with a reference instrument—is a common practice in IoT device testing and system monitoring studies to ensure that device performance meets design claims and established fault tolerances (e.g., in sensor and data quality studies, error and drift measurements are often examined as part of validation).

Table 2. Test Results of the Device

Parameter	Error Percentage Result, Test No.			Average
	1	2	3	
Ultrasonic Sensor	2,21 %	2,85 %	8,1 %	4,38 %
pH Sensor	2,4 %	5,65 %	6,04 %	4,69 %
TDS Sensor	1,7 %	1,3 %	2,3 %	1,76 %

Based on the feasibility interval presented in Table 1, the device evaluation using the comparison test method indicated high feasibility. The assessment, conducted with subject-matter experts from the Makassar Aviation Polytechnic, confirmed that the system's measurement results are highly consistent with the actual values, thereby validating its accuracy and reliability. These findings are aligned with previous studies that emphasize the importance of feasibility testing as a critical step to ensure system validity and practical applicability in engineering and educational contexts (Al-Fuqaha et al., 2015; Gubbi et al., 2013; Hossain & Muhammad, 2016).

CONCLUSION

This research successfully designed and implemented an IoT-based water level and quality monitoring system, achieving the primary objective of integrating ultrasonic, pH, and TDS sensors with an ESP32 microcontroller. The empirical results demonstrate that the prototype provides reliable real-time data transmission via the Thinger.io platform, ensuring high accuracy in local and remote monitoring. Beyond its technical performance, this system offers a significant pedagogical contribution as an innovative learning medium for the Mechatronics course at Makassar Aviation Polytechnic. It bridges the gap between theoretical frameworks and industry-driven practical skills, particularly in sensor integration, microcontroller programming, and cloud-based data visualization.

The study concludes that implementing such IoT systems effectively enhances students' readiness for the technological demands of Industry 4.0. However, despite its robust functionality, the current system is limited in the range of water quality parameters it covers. Therefore, further development is recommended to include sensors for temperature, turbidity, and dissolved oxygen to provide a multidimensional assessment of water integrity. Future research should also focus on improving energy efficiency and scalability through the integration of mobile applications. Finally, incorporating Artificial Intelligence (AI) for predictive analytics could transform the system from a real-time monitoring tool into a proactive decision-support framework. Overall, this prototype serves as both a practical solution for water management and a strategic educational asset in the field of aviation mechatronics.

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