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Design and Development of an ESP32-Based Rubber Latex Acidity (pH) Tester with LED Indicator

Kemas Muhammad Wahyu Hidayat[1]*, Dwi Retno Aji[2]
[1, 2]Information Technology Study Program, Faculty of Engineering, Universitas Muhammadiyah Palembang, Indonesia
[1*] wahyu_hidayat@um-palembang.ac.id, [2]dwiretnoaj2@gmail.com

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***Corresponding Author**

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ABSTRACT

Rubber latex quality is closely related to acidity (pH), because a decrease in pH can reduce colloidal stability and accelerate premature coagulation. In field conditions, latex pH monitoring is still limited, making changes in quality difficult to detect quickly. This study aims to develop a portable latex pH measurement system based on ESP32 that integrates Fuzzy Logic, LED status indicators, and an Internet of Things (IoT) monitoring dashboard. The research uses a quantitative approach with Research and Development (R&D) as the development method. Primary data were obtained from calibration tests using pH 4.01, 6.86, and 9.18 buffer solutions, response-time and stability tests, LED classification tests, and field tests on latex under different conditions. The results show that the sensor achieved 100% accuracy at pH 4.01, 97.96% at pH 6.86, and 99.68% at pH 9.18. The response test showed that the reading approached a stable value within a short measurement interval, while the stability test produced a consistent reading of 4.01 between 40 and 60 seconds. The LED output was consistent with the system classification, with red for poor, yellow for critical, and green for normal conditions. Fresh latex was measured at pH 6.93 and classified as normal, while stored latex showed a decrease in pH and was classified as critical. The developed system can therefore support real-time and remote monitoring of latex quality.

INTRODUCTION

The development of the Internet of Things (IoT) has encouraged the integration of sensors, microcontrollers, communication networks, and monitoring applications to produce faster and connected measurement systems. IoT enables devices to collect and transmit data automatically so that information can be monitored remotely (Nahdi & Dhika, 2021). The ESP32 is suitable for this purpose because its WiFi connectivity supports network-based monitoring systems (Aryatama & Samsugi, 2024). These technologies have also been applied in agriculture and other monitoring fields, where timely information supports operational decisions.

Rubber latex is a colloidal system whose stability is affected by environmental conditions and acidity. Under ideal conditions, the pH of fresh latex is approximately 6.8–7.0. A decrease in pH can reduce the stability of rubber particles and increase the risk of coagulation before processing. Rubber remains an important commodity, and quality management is relevant to the competitiveness of natural-rubber production (Fajriyah et al., 2024). Therefore, pH is an important parameter for helping users identify latex condition and respond more quickly.

The problem in Air Limau Village is the lack of a practical instrument for objectively measuring rubber latex pH while providing immediate and remote quality information. Recent studies have demonstrated the feasibility of ESP32-based pH monitoring and IoT data transmission in water-quality applications (Manurung et al., 2022; Pinandhita et al., 2024; Yunarty et al., 2024). Other studies have combined ESP32, pH sensing, and fuzzy classification to support automated interpretation of changing pH conditions (Prayoga, 2025; Handinata & Khoirunnisaa, 2026). However, these systems focus on water or hydroponic media rather than rubber latex. Therefore, a field-oriented system that measures latex pH, classifies its condition, and provides both local and remote information remains relevant.

Based on these gaps, this study developed an ESP32-based latex acidity tester that integrates a pH sensor, Fuzzy Logic, LED indicators, Firebase Realtime Database, and an Android dashboard. Fuzzy Logic was used to interpret pH values into quality status so that values in transition regions were not treated only as rigid boundaries. The contribution of this study is a prototype that integrates measurement, classification, visual warning, and remote monitoring within a single system. The study aimed to evaluate the device's ability to measure pH, determine quality status, provide appropriate LED indications, and present data in real time on the dashboard.

LITERATURE REVIEW

Recent pH-monitoring research has increasingly combined sensor calibration, microcontroller processing, and IoT communication. Manurung et al. (2022) developed an ESP32-based system for real-time monitoring of tap-water quality using pH, temperature, and turbidity sensors, supported by Firebase and MIT App Inventor. Pinandhita et al.

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(2024) designed and tested an IoT-based pH and temperature sensor for monitoring tofu-industry wastewater. Yunarty et al. (2024) developed a pH-water monitoring and control system for hydroponics using an application-based interface. These studies show that pH measurement can be connected to remote monitoring, although their measurement objects and system purposes differ from rubber latex.

More recent studies have also applied fuzzy methods to interpret sensor readings. Tundo et al. (2024) integrated an ESP32 microcontroller, IoT, and a fuzzy algorithm for plant-watering monitoring. Prayoga (2025) developed an ESP32-based monitoring and control system for pond-water oxygen and pH using fuzzy logic, while Handinata and Khoirunnisaa (2026) combined ESP32, pH sensors, and Mamdani fuzzy logic for monitoring and stabilizing aquaculture-water pH. Budi et al. (2025) reported high accuracy in an Arduino-based pH and temperature measuring instrument. Sari et al. (2021) also examined a digital pH measuring instrument, while Wisnu et al. (2025) applied fuzzy logic to pH and temperature control. Although these studies provide relevant approaches, they do not specifically classify rubber latex quality while combining the result with LED warnings and an Android dashboard.

Fuzzy Logic was selected because it represents input values through degrees of membership and can therefore interpret transition conditions rather than relying only on rigid binary thresholds. Recent ESP32-based monitoring studies have applied fuzzy inference to convert sensor readings into actionable status information (Tundo et al., 2024; Prayoga, 2025; Handinata & Khoirunnisaa, 2026). ESP32 was selected as the processing and communication unit because it supports WiFi connectivity for IoT applications (Aryatama & Samsugi, 2024). The present study applies this integration to rubber latex and uses three output categories—poor, critical, and normal—to support field interpretation.

METHOD

This study used a quantitative approach with the Research and Development (R&D) method. The method was selected because the research focused on developing a product in the form of a pH testing device and evaluating its technical effectiveness. The R&D stages included problem identification, hardware and software design, implementation, testing, and evaluation. This development approach is consistent with the nature of the study, which produced a prototype and evaluated its performance progressively (Siregar, 2025).

The study was conducted at a rubber plantation in Air Limau Village. Primary data were obtained from pH sensor readings connected to the ESP32, calibration testing, response-time testing, stability testing, LED indicator testing, and direct testing on latex under different conditions. Secondary data were obtained from literature on latex, pH, sensors, ESP32, IoT, and Fuzzy Logic. Before sample testing, the sensor was calibrated using pH buffer solutions of 4.01, 6.86, and 9.18. The measured values were compared with the standard values to obtain error and accuracy. The error calculation used the following equation.

$$\text{Error (\%)} = |\text{Actual Value} - \text{Measured Value}| \,/\, \text{Actual Value} \times 100$$
$$\text{Accuracy (\%)} = 100 - \text{Error (\%)}$$

The hardware consisted of a pH sensor, ESP32, three indicator LEDs, current-limiting resistors, and supporting circuitry. The sensor generated an analog signal that was read by the ESP32. The microcontroller then processed the pH value using Fuzzy Logic. The classification result was used to control the red, yellow, and green LEDs. At the same time, the pH value and quality status were transmitted via WiFi to Firebase Realtime Database and displayed on an Android dashboard developed using MIT App Inventor.

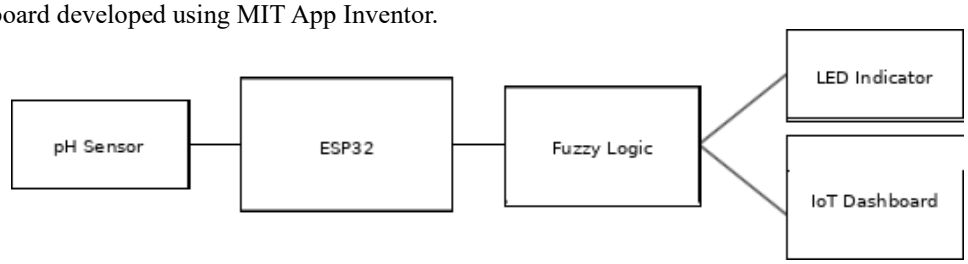


Figure 1. Architecture of the ESP32-based rubber latex pH testing system

The system architecture in Fig. 1 shows the pH sensor as the input, the ESP32 as the controller, Fuzzy Logic as the decision-making component, and the LED indicators and IoT dashboard as the outputs. In the fuzzy process, the pH value was transformed through fuzzification, evaluated using an IF–THEN rule base, and then processed through defuzzification to obtain the quality status. The rule base consisted of low pH conditions producing poor status with a red LED, medium pH conditions producing critical status with a yellow LED, and high pH conditions producing normal status with a green LED.

Repeated testing was conducted to evaluate accuracy, response speed, stability, classification conformity, and the system's ability to detect changes in latex condition. Field evaluation was performed on fresh latex, latex in a critical condition, and stored latex. The test results were compared with the actual latex condition and the outputs of the LED

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indicators and dashboard.

RESULT

The results showed that the latex acidity testing prototype was successfully realized by integrating a pH sensor, ESP32, Fuzzy Logic, LED indicators, Firebase Realtime Database, and an Android dashboard. The main unit was assembled in a box to protect the electronic components from liquids and moisture and to facilitate moving the device to latex collection sites. Three LEDs were placed on the front of the box as visual outputs of quality conditions. The implemented device is shown in Fig. 2.

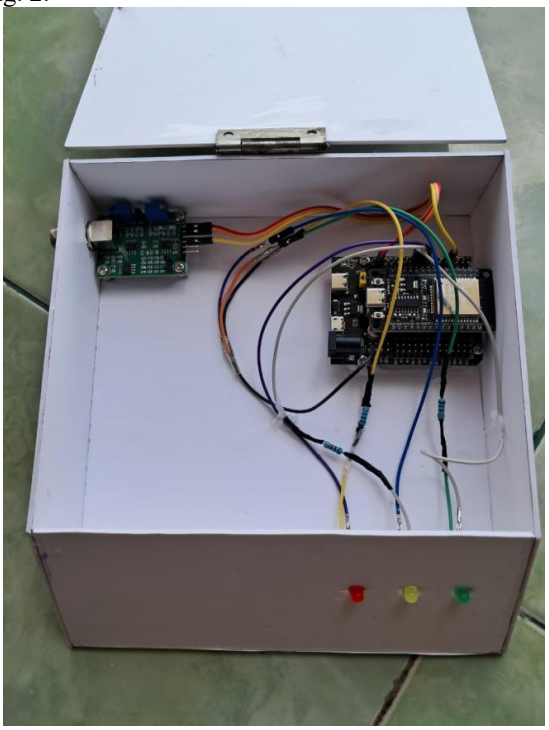


Figure 2. Main unit of the ESP32-based rubber latex pH tester

On the software side, the ESP32 ran a program to read the sensor, process the pH value, determine the status using Fuzzy Logic, control the LEDs, and transmit data through WiFi. Firebase was used to store pH values and quality status so that measurement data could be retained as historical records. The Android dashboard displayed the pH value and quality status directly, as shown in Fig. 3. This integration allowed the information to be monitored without requiring the user to be near the device.



Figure 3. Rubber latex pH monitoring dashboard

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Calibration testing was performed using three buffer solutions. The results are presented in Table 1. For the pH 4.01 buffer, the device read 4.01, resulting in 0% error and 100% accuracy. For the pH 6.86 buffer, the device reading was 6.72, with 2.04% error and 97.96% accuracy. For the pH 9.18 buffer, the device reading was 9.15, with 0.32% error and 99.68% accuracy. These results indicate that the sensor provided high accuracy across the tested pH range.

Table 1. pH sensor calibration and accuracy results

No.	Standard Solution	Measured pH	Error	Accuracy
1	pH 4.01	4.01	0%	100%
2	pH 6.86	6.72	2.04%	97.96%
3	pH 9.18	9.15	0.32%	99.68%

Response-time testing was performed using the pH 4.01 buffer by recording the value from the moment the sensor was immersed until the reading became stable. The data in Table 2 show an initial value of 4.29 at the fourth second that gradually approached the reference value, reaching 4.01 at the 40th second and remaining at 4.01 at the 44th second. The average reading during the test was 4.09.

Table 2. Sensor reading response-time test results

No.	Time (seconds)	pH Value
1	4	4.29
2	8	4.21
3	12	4.15
4	16	4.11
5	20	4.08
6	24	4.06
7	26	4.04
8	32	4.03
9	36	4.02
10	40	4.01
11	44	4.01
Average		4.09

Stability testing was performed after the reading reached a stable condition. As shown in Table 3, the readings at 40, 44, 48, 52, 56, and 60 seconds were all 4.01. This consistency indicates that the sensor was able to maintain its reading under the same solution conditions without significant changes.

Table 3. Sensor reading stability test results

No.	Time (seconds)	pH Value
1	40	4.01
2	44	4.01
3	48	4.01
4	52	4.01
5	56	4.01
6	60	4.01

LED indicator conformity was tested using several pH values. The results in Table 4 show that pH 4.01 was classified as poor and activated the red LED, pH 6.20 was classified as critical and activated the yellow LED, while pH 9.18 was classified as normal and activated the green LED. All results were considered consistent with the system classification.

Table 4. LED indicator conformity test results

No.	pH Value	System Classification	LED Activated	Conformity
1	pH 4.01	Poor	Red	Consistent
2	pH 6.20	Critical	Yellow	Consistent
3	pH 9.18	Normal	Green	Consistent

Field testing was conducted under several latex conditions. For fresh latex, the device measured pH 6.93 and the system provided a normal status with a green LED and a normal status in the application. For latex that had undergone changes, the pH value decreased and the system provided a critical status with a yellow LED. Stored latex also showed a decrease in pH and was classified as critical. The physical condition of the stored sample showed a darker color and a texture that had begun to coagulate. An example of the field test is shown in Figure 4.

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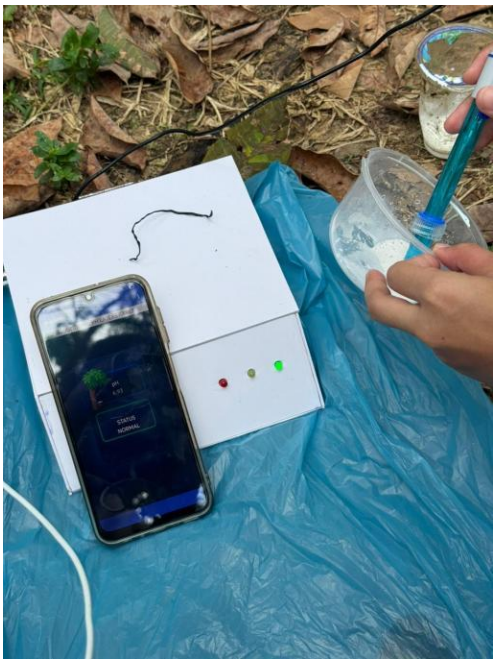


Figure 4. Field testing of the device on rubber latex

Overall, the test results show that the system was able to perform measurement, classification, visual warning, and information presentation in an integrated manner. The highest accuracy was obtained for the pH 4.01 and pH 9.18 buffers, while the largest deviation occurred at pH 6.86 with 2.04% error.

DISCUSSION

The results demonstrate that integrating the ESP32 and pH sensor can produce a sufficiently accurate measurement system to support rubber latex monitoring. Accuracies of 100% for pH 4.01, 97.96% for pH 6.86, and 99.68% for pH 9.18 indicate that the sensor can operate from acidic to alkaline conditions. The largest deviation occurred near the neutral condition. This is important because the ideal pH range of fresh latex is close to neutral, making calibration and sensor stability important components of the system.

The sensor accuracy obtained in this study is comparable to results reported in recent pH-measurement research. Budi et al. (2025) reported 99.62% accuracy for an Arduino Uno-based pH and temperature measuring instrument. Manurung et al. (2022) also demonstrated the use of an ESP32 and pH sensor for real-time water-quality monitoring, while Pinandhita et al. (2024) integrated pH and temperature sensing with IoT for industrial wastewater monitoring. Handinata and Khoirunnisaa (2026) reported an average error of 0.91% in their ESP32-based pH and temperature monitoring system. Direct numerical comparison should be interpreted cautiously because the sample media, sensors, calibration procedures, and test conditions differ. The contribution of the present system is its application to rubber latex and its integration of pH measurement, fuzzy classification, LED warnings, and remote monitoring.

The response test showed that the reading gradually changed from 4.29 to 4.01. This pattern indicates the sensor stabilization process when the electrode was first placed in the solution. After reaching a stable condition, the reading remained at 4.01 throughout the stability test. This consistency is important because the sensor value serves as an input to the Fuzzy Logic process. Excessive fluctuations could cause the quality status to change repeatedly and reduce the clarity of information provided to users.

Fuzzy Logic provides a way to convert numerical pH readings into quality information that is easier for users to interpret. Recent ESP32-based systems have used fuzzy inference to classify or control pH-related conditions in aquaculture and other monitoring applications (Tundo et al., 2024; Prayoga, 2025; Handinata & Khoirunnisaa, 2026). In the present system, the fuzzy process determines poor, critical, or normal status before the result is sent to the LEDs and dashboard. This integration provides two forms of information: an immediate visual warning through the LED and numerical readings with status information through a smartphone.

The field test results also showed a relationship between storage time and changes in pH. Fresh latex produced a pH of 6.93 and was categorized as normal, whereas latex that had undergone storage showed a decrease in pH and entered the critical category. This finding strengthens the function of the system as a tool for monitoring quality changes rather than merely as a pH meter. In field conditions, the ability to detect changes at an early stage may help users determine whether latex handling is needed before its quality deteriorates further.

Nevertheless, the system has several limitations. The study did not integrate a temperature sensor as a compensation parameter, even though temperature is an important consideration in sensor measurement and calibration

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(Agustinur et al., 2024; Budi et al., 2025). The dashboard could also be further developed with more comprehensive historical graphs and an early-warning notification system. In addition, the study used a WiFi connection for data transmission, so remote monitoring performance still depends on network availability. These limitations provide opportunities for further development to improve the reliability of the system for field use.

CONCLUSION

This study produced an ESP32-based rubber latex acidity testing prototype that integrates a pH sensor, Fuzzy Logic, LED indicators, Firebase Realtime Database, and an Android dashboard. Calibration results showed accuracies of 100% at pH 4.01, 97.96% at pH 6.86, and 99.68% at pH 9.18. The response test showed that the reading approached a stable condition within a relatively short measurement period, while the stability test produced a consistent reading of 4.01 over 40–60 seconds. The system classification also corresponded to the LED indicators: red for poor, yellow for critical, and green for normal. In field testing, fresh latex with a pH of 6.93 was classified as normal, whereas stored latex showed a decrease in pH and was classified as critical. These results demonstrate that the system can perform integrated and real-time measurement, classification, visual warning, and monitoring. The main contribution of this study is the provision of a more objective and informative tool for monitoring latex quality. Future development should consider temperature sensing, more comprehensive historical graphs, early-warning notifications, and a more stable cloud platform.

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