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Real-Time and Accurate pH Sensor Based on Internet of Things (IoT)

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Abstract

One important parameter that needs to be considered in water quality is the acidity level (pH) in the water. This study aims to design and determine real-time and accurate pH sensor based on internet of thing (IoT). This system design uses an ESP32 microcontroller and The PH-4502C pH Meter Module sensor. The ESP32 can be connected to the IoT-based Blynk platform, allowing pH data to be monitored in real time via a smartphone. Testing of the IoT-based pH sensor was conducted to evaluate the system's real-time operation under varying distances. Meanwhile, the pH sensor's accuracy was determined by comparing its output with a digital pH meter using buffer solutions at different pH levels. The test results show that the time value required in each range is always constant, namely 1 s. This proves that IoT-based monitoring does not affect the range. Meanwhile, measurement of pH level was the average error value is 3.49%, and the sensor accuracy is 96.51%. These results indicate a low error rate, resulting in high accuracy. The sensor error value of 3.49% is lower than the specified error tolerance limit of <5%. This proves that the pH sensor, with an accuracy of 96.51%, is suitable and reliable for measuring pH in solutions.

Keywords: *Accurate; IoT; pH; Real-time; Sensor*

1. Introduction

Water is an indispensable primary need in the daily lives of living creatures on Earth, including humans, animals, and plants. Water is used for various basic needs, such as drinking, bathing, washing household utensils and clothes, cooking, watering plants, washing vehicles, cleaning floors, cooling engines, and as a solvent for materials. Clean water is essential for human survival because without access to it, survival cannot be sustained. One important parameter that needs to be considered in water quality is the acidity level (pH) in the water [1][2]. Physical standards for clean water quality have been established and regulated by Minister of Health Regulation No. 492 of 2010 concerning drinking water requirements [3].

According to a report from the Head of the National Land Agency (*Badan Pertanahan Nasional* = BPN) of Gorontalo Province in 2020, 3,369.91 hectares of land had been converted into residential areas, offices, plantations, livestock farms, and other uses, which has resulted in a decline in water quality [4]. The decline in water quality is primarily caused by environmental factors and increased unwise human activities that have resulted in the pollution of water sources. This condition occurs when water carries a pollution load that exceeds its natural capacity [5][6]. This situation has attracted the attention of several researchers seeking solutions for water quality monitoring, including those based on the Internet of Things (IoT). IoT is a concept that integrates various devices into an internet network, allowing these devices to communicate with each other via an internet connection [7].

Several studies have been conducted on the development of water quality testing tools, such as the study by [8], which used engineering research methods to modify and rearrange components in the system. In this study, a prototype tool for monitoring water pH and controlling IoT-based aquaponic cultivation was developed. Meanwhile, developed an IoT-based water quality monitoring system that integrates fuzzy logic to determine the cleanliness level of a water sample using a pH sensor [9]. Meanwhile, tested pH using litmus paper and physical parameters [6]. Some of the weaknesses mentioned above include the complexity of using the tool, instability in measurement values due to periodic sensor calibration, and the inability to assess accuracy and real-time performance.

Considering the importance of water quality in various sectors, researchers are interested in developing an IoT-based water quality testing tool that uses pH as a parameter. This tool is designed with the principles of ease of manufacture, affordability, and real-time data. Furthermore, the primary focus of this development is to improve measurement accuracy, resulting in more reliable results.

2. Methodology

This system design uses an ESP32 microcontroller as a data-processing centre, connected to an analogue pH sensor. The PH-4502C pH Meter Module sensor produces a signal in the form of an analogue voltage that changes according to the acidity level (pH) of the solution. The sensor output voltage is then connected to the ADC (Analogue-to-Digital Converter) pin on the ESP32, allowing the ESP32 to convert the analogue signal into digital data. The pH sensor is equipped with a signal conditioning module that stabilises and adjusts the sensor output voltage to match the ADC range. The ADC data is then processed in a program in the Arduino IDE, where calibration is performed using a voltage-to-pH conversion equation to obtain a pH value, ensuring the displayed value is close to the actual condition. The processed pH value is then displayed on a laptop's serial monitor for observation.

In addition, the ESP32 can be connected to the IoT-based Blynk platform, allowing pH data to be monitored in real time via a smartphone. Thus, this system works by starting with pH measurement by the sensor, data processing by the ESP32, and displaying data on IoT-based monitoring media via the observer's smartphone. The research flowchart is shown in Figure 1. Testing of the IoT-based pH sensor was conducted to evaluate the system's real-time operation under varying distances. Meanwhile, the pH sensor's accuracy was determined by comparing its output with a digital pH meter using buffer solutions at different pH levels.

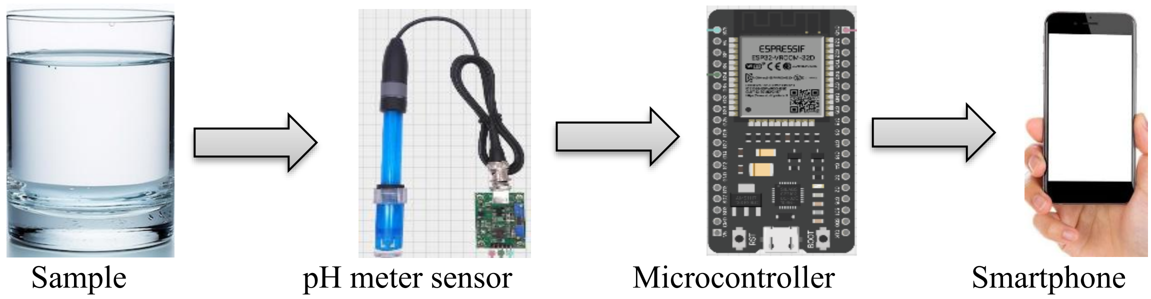

Figure 1. Research flowchart of pH sensor based on IoT

3. Results and Discussion

Testing of a pH sensor based on an IoT was applied to water quality testing using a constant pH sample of 6.5. This testing was conducted to ensure the sensor design could operate in real time. Testing was performed using varying distance ranges, as shown in Figure 2.

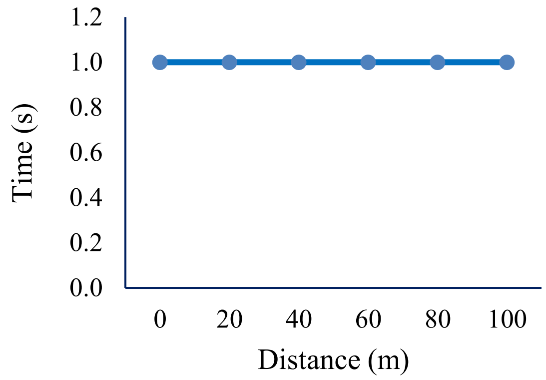

Figure 2. Real-time testing of pH sensor based on an IoT

Figure 2 shows a test graph of pH sensor based on an IoT to determine whether it can operate in real-time. monitoring based on IoT is carried out over a range of distances, namely 0 m to 100 m, with a 20 m interval. The test results show that the time value required in each range is always constant, namely 1 s. This proves that IoT-based monitoring does not affect the range. IoT-based monitoring applications can be deployed anywhere, so responses will be in real time as long as the IoT application remains within a good internet connection. In addition to ensuring that the IoT-based pH sensor can operate in real time, the pH sensor must also be verified to work reliably by determining its accuracy through comparisons between the values produced by the digital pH meter and the output of the designed pH sensor. The comparison between the digital pH meter and pH sensor output is shown in Figure 3.

Based on Figure 3 shows a calibration graph comparing the pH values read by the digital pH meter with those produced by the ESP32-based pH sensor in three test samples. In the first sample, the digital pH meter showed 5.12, while the pH sensor showed 4.89. This difference indicates a reading difference of around ±0.23, but it is still relatively small for an analogue sensor. In the second sample, the digital pH meter read 6.94, while the sensor read 7.34, resulting in a larger deviation of ±0.40. The electrode's sensitivity, the stability of the signal conditioning circuit, and the influence of external factors, such as solution temperature, can all contribute to this.

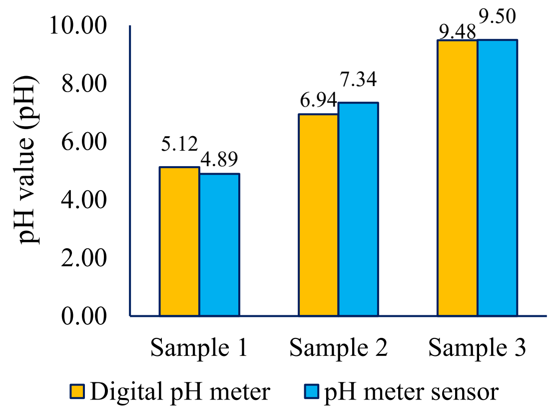

Figure 3. Comparison of pH values

In the third sample, the digital pH meter read 9.48, and the sensor read 9.50, with a minimal difference of ±0.02, indicating that the sensor performs well in the alkaline pH range. Overall, the graph shows that the trend in sensor values is in line with the reference tool, indicating that the calibration process is successful and the sensor shows good accuracy. Minor deviations that still appear can be corrected through periodic calibration and resetting the multiplier and sensor offset. These results are consistent with previous research indicating that glass electrode-based pH sensors exhibit linear behaviour with changes in hydrogen ion concentration but still require two or more point calibrations to achieve optimal accuracy [10]. Furthermore, other research reports that the use of microcontrollers, such as the ESP32, can improve the stability of pH sensor readings through digital signal processing [11]. The results of determining the pH sensor's error and accuracy are shown in Table 1.

Table 1. Accuracy values of pH sensors

Sample	Digital pH Meter (pH)	pH Sensor (pH)	Error (%)	Accuracy (%)
1	5.12	4.89	4.49	95.51
2	6.94	7.34	5.76	94.24
3	9.48	9.50	0.21	99.79
Average			3.49	96.51

Table 1 shows that the pH sensor can measure the pH of standard solutions with fairly good agreement with the digital pH meter, the reference tool. However, there are still deviations in some measurements. In a pH 5.12 buffer solution, the sensor reads 4.89 with an error of 4.49% and an accuracy of 95.51%, while in a pH 6.94 buffer solution, the sensor reads 7.34 with the highest error of 5.76% and an accuracy of 94.24%. Meanwhile, in a pH 9.48 buffer solution, the sensor shows the best performance with a reading value of 9.50, an error of only 0.21%, and an accuracy of 99.79%. These results indicate that the sensor has a more stable response in the alkaline pH range, whereas at acidic to neutral pH, larger reading discrepancies are still observed. These findings align with previous research, which reported that microcontroller-based pH sensors generally achieve an accuracy of around 95% with an error of 4–5% across the acidic-neutral pH range [12]. Differences in error values can be caused by the pH electrode's sensitivity, which is affected by environmental conditions and temperature; a suboptimal sensor stabilisation process; and the possibility of nonlinearity in sensor characteristics at specific pH ranges. Furthermore, the calibration process significantly affects reading accuracy, so even minor errors in adjusting the reference value can affect measurement results. This is consistent with research findings that pH sensor calibration with standard buffer solutions can significantly improve sensor reading accuracy [13]. Overall, based on Table 1, the average error value is 3.49%, and the sensor accuracy is 96.51%. These results indicate a low error rate, resulting in high accuracy. The sensor error value of 3.49% is lower than the specified error tolerance limit of <5% [14]. This proves that the pH sensor, with an accuracy of 96.51%, is suitable and reliable for measuring pH in solutions.

4. Conclusion

Testing of pH sensor based on an IoT to determine whether it can operate in real-time. The test results show that the time value required in each range is always constant, namely 1 s. This proves that IoT-based monitoring does not affect the range. IoT-based monitoring applications can be deployed anywhere, so responses will be in real time as long as the IoT application remains within a good internet connection. Meanwhile, measurement of pH level was the average error value is 3.49%, and the sensor accuracy is 96.51%. These results indicate a low error rate, resulting in high accuracy. The sensor error value of 3.49% is lower than the specified error tolerance limit of <5%. This proves that the pH sensor, with an accuracy of 96.51%, is suitable and reliable for measuring pH in solutions.

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