Development Of Smart pH Prototype with FTTH Network Integration for Smart Chemistry Laboratory

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ABSTRACT

Chemistry laboratories at the secondary education level have a vital role in supporting learning and research. However, manual management often faces obstacles in efficiency, accuracy, and data accessibility. Following the Regulation of the Minister of National Education Number 24 of 2007, pH meters are mandatory equipment in high school chemistry laboratories. However, conventional tools are often inadequate for precise real-time measurements. This study developed a Smart pH system integrating the Internet of Things (IoT) and fiber-to-the-home (FTTH) technology for real-time pH measurement. This system was designed using a pH-4502C sensor, Arduino Uno, NodeMCU ESP8266, and Arduino Cloud and tested on five types of solutions relevant to the high school chemistry curriculum, including salt solution, vinegar, lime, liquid soap, and mineral water. The test results showed an average accuracy of 99% and a 1-1.6 seconds data transmission delay. The total loss of the FTTH network was 3.65 dB, within the ITU-T G.984 standard limit. This research supports the fulfillment of national standards and improves the efficiency and reliability of pH measurements, opening up opportunities for further innovation in chemistry education laboratory automation in Indonesia.

Keywords : Smart pH Prototype; IoT; FTTH Network Integration; Smart Chemistry Laboratory.

Article History

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I. INTRODUCTION

Technological transformation has penetrated various sectors, including laboratories, in today's digital era. Laboratories in educational institutions support academic activities, both in the form of closed and open spaces, which are structured for special purposes such as research, experimentation, testing, and community service [1]. Previously, manual laboratories were optimized completely through automation and data connectivity [2]. This led to the emergence of the smart laboratory concept, a global trend that integrates information and communication technology to improve efficiency, accuracy, and data accessibility in chemical research [3][4]. Chemical laboratories are places where various types of chemical research and experiments are carried out. Implementing chemical laboratories requires various equipment and chemicals to be managed properly to function optimally and safely [5]. One of the important parameters in chemical analysis is pH measurement, which is vital in various biological and chemical processes and experiments [6].

Education regulations in Indonesia further strengthen the urgency of developing a more sophisticated pH measurement system in chemistry laboratories. The Regulation of the Minister of National Education (PERMENDIKNAS) Number 24 of 2007 concerning Facilities and Infrastructure Standards for Elementary/Madrasah Ibtidaiyah Schools (SD/MI), Junior High Schools/Madrasah Tsanawiyah (SMP/MTs), and Senior High Schools/Madrasah Aliyah (SMA/MA) explicitly lists the pH meter as one of the mandatory equipment in chemistry laboratories. This regulation emphasizes the importance of pH measurement in chemistry learning and research at the secondary education level [7]. Therefore, developing a more sophisticated pH measurement system is not only in line with the global trend of smart laboratories but also supports efforts to improve the quality of chemistry education following Indonesian national standards.

Globally, the Internet of Things (IoT) has become the backbone of the industrial revolution 4.0, enabling device interconnection and real-time data exchange [8]. The application of IoT in chemistry laboratories offers great potential to maximize experimental processes, improve measurement precision, and facilitate remote monitoring [9]. Meanwhile, fiber-to-the-home (FTTH) technology has changed the telecommunications landscape by providing high-speed and low-latency connectivity, crucial for real-time data transmission in the context of smart laboratories [10].

Several previous studies have demonstrated the successful application of IoT in water quality monitoring and pH measurement. [11] Developed an IoT-based water quality monitoring system for Asian Seabass aquaculture using low-cost sensors with improved accuracy through simple linear regression, resulting in measurement accuracy of up to 97%. [12] Used ESP32 to track water pH and turbidity through the Blynk IoT app, demonstrating the system's effectiveness in maintaining optimal conditions for ornamental fish. [13] Implemented an IoT-based water monitoring system for PAMSIMAS with a success rate of 86.6%. [14] Developed an IoT monitoring system for water temperature, pH, and TDS with high accuracy (98.28-100%) compared to SNI standards. [15] Integrated an IoT sensor with an Arduino board and communication module to measure water quality parameters, such as temperature, pH, and dissolved oxygen (DO), for aquaculture. It achieved a high level of accuracy, with a maximum error of 4.87%, indicating a system success rate of 95.13%.

Although previous studies have shown the great potential of IoT in improving the accuracy and efficiency of pH measurement, an in-depth analysis of these studies reveals some important gaps that need to be addressed. First, most previous studies focus on IoT implementation without considering integration with high-speed network technologies such as FTTH [16]. This leaves the important question of how system performance can be improved by integrating more advanced network infrastructures, especially in the real-time data transmission required for pH measurements in modern chemistry laboratories.

In addition, while there is much research on IoT-based water quality monitoring, there is still a lack of research specifically applying this technology in the context of smart chemistry laboratories for real-time pH measurement. This gap points to the need for more research focused on specific applications of IoT in the chemistry laboratory environment, where the accuracy and speed of pH measurements significantly impact experimental and analytical results.

Furthermore, previous studies have generally focused on measurement accuracy but less on delay analysis and system reliability related to real-time data transmission. This aspect is particularly important in a laboratory environment where the timeliness and consistency of measurements can affect the validity of research results. Therefore, a comprehensive analysis of system delay and reliability is needed to ensure that the implemented technology meets the stringent standards required in chemical research.

Finally, no research has explicitly explored the potential synergy between IoT and FTTH technologies in improving the performance of pH measurement systems in chemical laboratories. Integrating these two technologies can improve measurement accuracy, speed, system reliability, and scalability. Exploration of these synergies can pave the way for developing a new generation of more advanced and efficient pH measurement systems for smart chemical laboratories.

In light of these deficiencies, this project aims to create a smart pH system incorporating IoT and FTTH technologies for real-time pH measurement in smart chemistry laboratories. The main focus will be on system implementation, performance analysis, and delay evaluation to ensure the reliability and effectiveness of the system in supporting modern chemical research and analysis activities.

This research aims to contribute significantly to developing a Smart chemistry laboratory by integrating IoT and FTTH technology in pH measurement. This system improves the efficiency and accuracy of pH measurement and paves the way for further innovation in the automation and digitalization of chemistry laboratories. In addition, the results of this research can improve the quality of learning and research in chemistry and support efforts to standardize and modernize chemistry laboratories in Indonesia following applicable regulations.

II. METHOD

This research adopts the Research and Development (R&D) method to create or develop a particular product and test its effectiveness [17]. In this context, the product developed is an IoT-based water pH measurement system. The R&D method was chosen because it follows the research objectives of producing an output in the form of an innovative water pH measurement system based on IoT technology to ensure the success of the research. The development process follows the stages of the established development model [18] based on Fig.1.

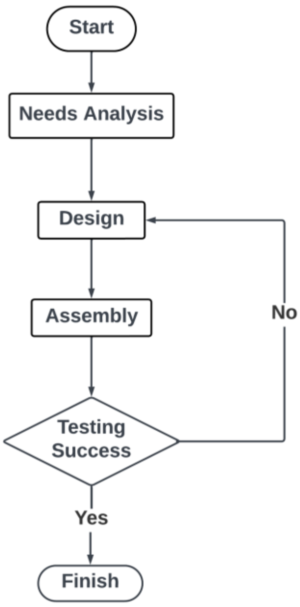

Fig.1. Flowchart of Development Model

The model development flow in Fig.1 consists of several main stages: analysis, design, assembly, and testing. If the test is successful, the development process is considered complete at the testing stage. However, if the test fails, the flow will return to the design stage to make the necessary improvements and adjustments.

A. Needs Analysis

Researchers conducted a needs analysis to determine the components required for this IoT system. Table I lists the components needed to create the Smart pH system, including hardware and software.

TABLE I
SMART PH SYSTEM SOFTWARE AND HARDWARE SPECIFICATIONS

Software	**Hardware**
Arduino IDE 1.8.19	Arduino Uno
Arduino Cloud	NodeMCU ESP8266
-	Sensor pH-4502C
-	LCD I2C 16 × 2
fig-	Breadboard Mini

Based on Table I, this Smart pH System was built using software and hardware. Regarding software, the system uses Arduino IDE 1.8.19 for programming and Arduino Cloud to monitor data online. As for the hardware, the system uses Arduino Uno as the main controller, NodeMCU ESP8266 for wireless communication, a pH-4502C sensor to measure pH level, a 16x2 I2C LCD to display data display, and a mini breadboard for connecting components [19].

$$P_r = P_t - \alpha_{total} \quad (1)$$

In addition, in the context of FTTH technology integration, the needs analysis also includes calculating loss in the FTTH network to ensure optimal data transmission quality. Based on the ITU-T G.984 standard, the maximum total loss allowed in the FTTH network is 28 dB [20]. In implementing the Smart pH system, the results of the FTTH loss calculation show a total loss with an average of 3.65 dB, which is included in the excellent category. The loss value is calculated using Equation (1), where P_r is the measured receive power, P_t is the transmitted transmit power, and α is the power loss value. These results are listed in Table II.

TABLE II
LOSS MEASUREMENT BETWEEN OPTICAL LINE TERMINAL (OLT) TO ROSET

Core Connection	P_t (dBm)	P_r (dBm)	α (dB)
Number 1	- 6.48	- 10.10	3.62
Number 2	- 6.86	- 10.54	3.68

The FTTH loss analysis results show that the network infrastructure used in the Smart pH system has met the standards and can support high-quality data transmission. This is important to enable real-time transmission of pH measurement data with low latency and high stability, following the needs of smart chemical laboratories.

B. Design

At this stage, an IoT-based water pH measurement system will be designed. Researchers made a system scheme that describes the interconnection between the pH sensor, microcontroller, IoT module, and user interface, which can be seen in Fig.2. Table III shows the pin allocation used for the smart pH system and the system process flow for pH measurement using Smart pH can be seen in Fig.3.

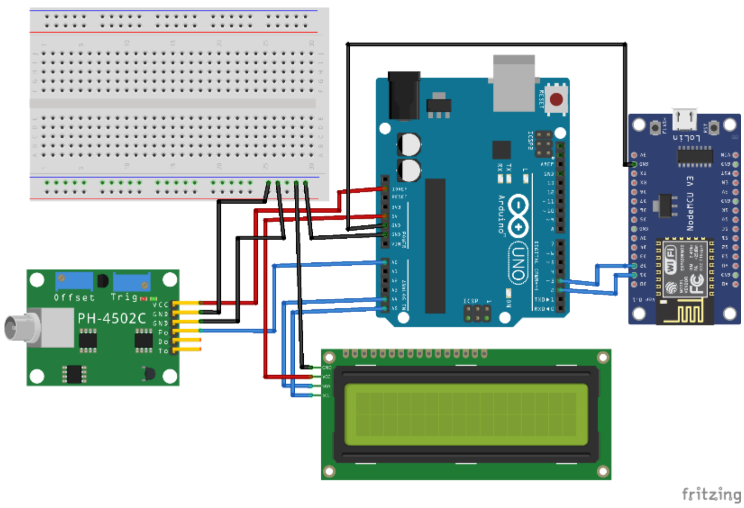

Fig.2. Smart pH System Circuit

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TABLE III
SMART PH SYSTEM PIN ALLOCATION

Component	Component Pin	Arduino Pin
Sensor pH-4502C	VCC	5V
	GND	GND
	GND	GND
	PO	A0
LCD I2C 16×2	GND	GND
	VCC	5V
	SDA	A4
	SCL	A5
NodeMCU ESP8266	GND	GND
	D1	D2
	D2	D3

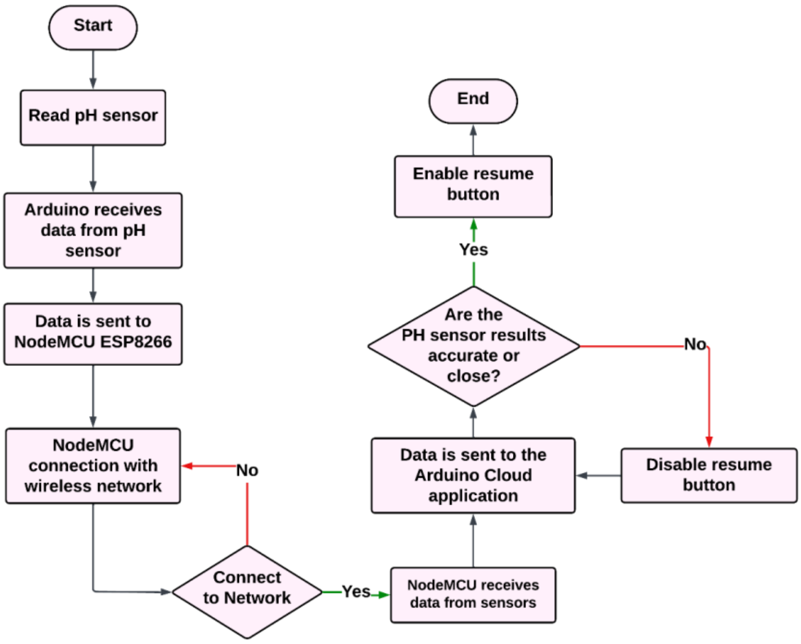

Fig.3. Smart pH System Flowchart

C. Assembly

At this stage, researchers assembled the IoT-based water pH measurement system according to the pre-made design, as shown in Fig.4. This included hardware integration and software development for the IoT system.

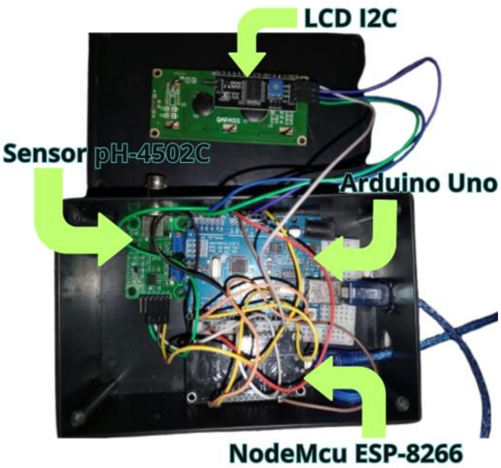

Fig.4. Smart pH Component Assembly Process

D. Testing

Based on SNI ISO/IEC 17025: 2017, before testing the pH of water, calibration is carried out on the developed smart pH meter and SNI pH meter using a standard pH Buffer solution [21]. Calibration is carried out with Buffer pH 4.00, 6.86, and 9.18 to ensure measurement accuracy in acidic, neutral, and alkaline pH ranges. Then for this test stage includes:

1) Comparison of pH measurement accuracy between the smart pH meter developed with the SNI pH meter.
2) Tests were conducted on five different water solutions based on materials commonly studied in grade 12 chemistry. These samples were chosen to test the performance of the Smart pH meter in the context of chemistry learning at the

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high school level. The composition of each solution sample is shown in Table IV. The solutions tested include salt, vinegar, lime juice, liquid soap, and Le Mineral water. These samples allowed for a comprehensive evaluation of the smart pH meter's ability to measure various acidity levels and basicity relevant to the high school chemistry curriculum [22].

TABLE IV
COMPOSITION OF WATER SOLUTION SAMPLES FOR PH TESTING

Sample Type	Water Volume	Mass/Solute
Water + Salt	100 ml	20 grams of NaCl
Water + Vinegar	100 ml	20 ml of vinegar
Water + Lime	100 ml	10 ml of lime
Water + Liquid Bath Soap	100 ml	20 ml of Liquid Bath Soap
Le Minerale Water	100 ml	-

3) Conduct 10 tests for each sample, with the duration of each test for 1 minute.
4) Recording the pH measurement results from both tools (smart and SNI pH meters).
5) Recording the time displayed on the LCD IoT smart pH meter and Arduino Cloud application.

Calculate the percentage error using Equation (2), where the *E* variable is the measurement error value, the *X* variable is the value of Smart pH, and the *XY* variable is the value of the SNI pH meter, then measure the accuracy using Equation (3), where *A* variable is the measurement accuracy value.

$$E\ (\%) = \left|\frac{XY - X}{XY}\right| \times 100 \quad (2)$$

$$A\ (\%) = 100 - E \quad (3)$$

Analyze the data transmission speed by comparing the time displayed on the IoT LCD and Arduino Cloud application using Equation (4), where the *D* variable is the delay value, the *Y* variable is the time displayed on the LCD, and the *Z* variable is the time displayed on the Arduino Cloud Application.

$$D = Y - Z \quad (4)$$

Data visualization uses a comparison graph of pH measurement results and a bar graph for the time difference between the IoT LCD and the Arduino Cloud application. Interpretation of the results includes analyzing the accuracy level of the smart pH meter and evaluating the speed and reliability of data transmission.

Through this R&D approach, the research aims to develop an IoT-based water pH measurement system and test its effectiveness in water pH measurement and IoT technology integration. Comprehensive testing and validation following national standardization bodies and supported by calibration using standard pH Buffer solution is expected to demonstrate that this system can be used effectively and reliably, focusing on performance comparison between the developed smart pH meter and SNI pH meter as a comparison standard.

III. RESULT AND DISCUSSION

After the three previous stages, the last stage of this research is the testing stage, which is the final result of system development. At this stage, the accuracy and error of the device in measuring the pH value will be tested, and the other is to test the data transmission delay in the prototype of the IoT-based Smart pH system, shown in Fig.5.

Fig.5. Compiled Smart pH Tool

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The first test focuses on comparing pH measurements between the Smart pH meter and the SNI pH meter using equations (1) and (2) to ensure the level of accuracy and error. Furthermore, the researcher used Equation (4) to compare the delay results between the LCD and the Arduino Cloud. A solution (*Larutan*) is a uniform mixture of substances formed by mixing at least two components in different proportions. The components in the solution consist of a substance in a smaller amount called a solute and a substance in a larger amount called a solvent. This study used pH 4.00 buffer solution, pH 6.86 buffer, and pH 9.18 buffer as calibration standards on the Smart pH and SNI pH meters according to the Directorate of National Standards for Thermoelectric and Chemical Measurement Units guidelines. The calibration process is shown in Fig.6 and 7.

(a) (b) (c)

Fig.6. Calibration Process of pH meter SNI Pena/Manufacturer: (a) Buffer Solution pH 4.00; (b) Buffer Solution pH 6.86; (c) Buffer Solution pH 9.18.

(a) (b) (c)

Fig.7. Smart-pH Calibration Process: (a) pH 4.00 Buffer Solution; (b) pH 6.86 Buffer Solution; (c) pH 9.18 Buffer Solution.

The next step after calibration is to test water solutions of vinegar, lime, Le Mineral, liquid soap, and salt. This test was carried out 10 times with a test time of 1 trial for 1 minute. At this stage, accuracy and error testing are also carried out using Equation (2) and Equation (3), then to evaluate the data transmission delay from the device to the IoT cloud platform using Equation (4), which aims to determine the speed and reliability of the system in real-time pH monitoring.

TABLE V
RESULTS OF PH MEASUREMENTS ON SALTWATER SOLUTIONS

Testing	Smart pH meter	pH meter SNI	Error (%)	Accuracy (%)
1	4.43	4.41	0.453514739	99.54648526
2	4.42	4.42	0	100
3	4.42	4.42	0	100
4	4.42	4.43	0.225733634	99.77426637
5	4.42	4.43	0.225733634	99.77426637
6	4.42	4.43	0.225733634	99.77426637
7	4.42	4.43	0.225733634	99.77426637
8	4.51	4.43	1.805869074	98.19413093
9	4.46	4.44	0.45045045	99.54954955
10	4.46	4.44	0.45045045	99.54954955
		Average (%):	0.406321925	99.59367807

TABLE VI
COMPARISON OF DATA DELIVERY TIME BETWEEN LCD AND ARDUINO CLOUD IN SALT WATER SOLUTION

Testing	LCD	Arduino Cloud	Delay (Second)
1	15:44:05	15:44:06	1
2	15:49:52	15:49:54	2

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Testing	LCD	Arduino Cloud	Delay (Second)
3	15:52:14	15:52:16	2
4	15:53:59	15:54:00	1
5	15:55:15	15:55:16	1
6	15:57:28	15:57:29	1
7	16:00:00	16:00:01	1
8	16:01:33	16:01:34	1
9	16:03:48	16:03:49	1
10	16:13:15	16:13:16	1
		Average:	1.2

Table V shows the comparison results of pH measurement in salt water solution. The error rate (% Error) shows an average error of 0.406%, with an average accuracy of 99.59%. Two tests had very accurate results, with a 100% accuracy rate in the second and third tests. These results indicate that the Smart pH Meter tool has excellent measurement performance. In addition, Table VI shows the recording time of measurement results on the LCD and Arduino Cloud with an average delay of 1.2 seconds. This indicates that data transmission to the Arduino Cloud is responsive and stable.

TABLE VII
RESULTS OF PH MEASUREMENTS ON VINEGAR WATER SOLUTION

Testing	Smart pH meter	pH meter SNI	Error (%)	Accuracy (%)
1	2.55	2.57	0.778210117	99.22178988
2	2.55	2.54	0.393700787	99.60629921
3	2.51	2.53	0.790513834	99.20948617
4	2.51	2.5	0.4	99.6
5	2.46	2.48	0.806451613	99.19354839
6	2.46	2.47	0.4048583	99.5951417
7	2.46	2.46	0	100
8	2.42	2.44	0.819672131	99.18032787
9	2.46	2.44	0.819672131	99.18032787
10	2.42	2.43	0.411522634	99.58847737
		Average (%):	0.562460155	99.43753985

TABLE VIII
COMPARISON OF DATA DELIVERY TIME BETWEEN LCD AND ARDUINO CLOUD IN VINEGAR WATER SOLUTION

Testing	LCD	Arduino Cloud	Delay (Second)
1	16:16:03	16:16:04	1
2	16:17:53	16:17:54	1
3	16:20:01	16:20:02	1
4	16:21:34	16:21:35	1
5	16:23:04	16:23:05	1
6	16:24:57	16:24:59	2
7	16:27:09	16:27:10	1
8	16:29:02	16:29:03	1
9	16:30:35	16:30:36	1
10	16:31:42	16:31:43	1
		Average:	1.1

Table VII shows the comparison results of pH measurement in vinegar water solution. The percentage error value (% Error) shows an average error of 0.562%, with an average accuracy of 99.43%. There was one very accurate test, with a 100% accuracy rate on the seventh test. These results show that the Smart pH Meter tool has excellent measurement performance. In addition, Table VIII shows the recording time of measurement results on the LCD and Arduino Cloud with an average delay of 1.1 seconds, which indicates that data transmission to the Arduino Cloud is quite responsive and stable.

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TABLE IX
RESULTS OF PH MEASUREMENTS ON LIME WATER SOLUTION

Testing	Smart pH Meter	pH meter SNI	Error (%)	Accuracy (%)
1	2.39	2.46	2.845528455	97.15447154
2	2.47	2.46	0.406504065	99.59349593
3	2.39	2.46	2.845528455	97.15447154
4	2.39	2.46	2.845528455	97.15447154
5	2.52	2.46	2.43902439	97.56097561
6	2.39	2.45	2.448979592	97.55102041
7	2.39	2.45	2.448979592	97.55102041
8	2.43	2.45	0.816326531	99.18367347
9	2.43	2.45	0.816326531	99.18367347
10	2.47	2.45	0.816326531	99.18367347
		Average (%):	1.87290526	98.12709474

TABLE X
COMPARISON OF DATA DELIVERY TIME BETWEEN LCD AND ARDUINO CLOUD ON LIME WATER SOLUTION

Testing	LCD	Arduino Cloud	Delay (Second)
1	11:42:38	11:42:36	2
2	11:45:06	11:45:05	1
3	11:46:42	11:46:40	2
4	11:47:31	11:47:30	1
5	11:39:33	11:39:31	2
6	11:53:38	11:53:37	1
7	11:55:10	11:55:08	2
8	11:56:09	11:56:07	2
9	11:57:38	11:57:36	2
10	11:59:17	11:59:16	1
		Average:	1.6

Table IX shows the pH measurement results for the lime solution. The Smart pH Meter accuracy rate is very high, with an average of 98.12% and an average percentage error of only 1.87%. This is a good smart pH meter that performs well in measuring acidic pH values. Table X shows the results of the delay between reading on the LCD and sending data to the Arduino Cloud, with an average delay of 1.6 seconds, indicating fast data transmission.

TABLE XI
RESULTS OF PH MEASUREMENTS ON LIQUID SOAP WATER SOLUTIONS

Testing	Smart pH Meter	pH meter SNI	Error (%)	Accuracy (%)
1	9.17	9.17	0	100
2	9.17	9.16	0.109170306	99.89082969
3	9.12	9.15	0.327868852	99.67213115
4	9.12	9.14	0.218818381	99.78118162
5	9.17	9.14	0.328227571	99.67177243
6	9.12	9.14	0.218818381	99.78118162
7	9.12	9.13	0.109529025	99.89047097
8	9.12	9.13	0.109529025	99.89047097
9	9.12	9.12	0	100
10	9.17	9.11	0.658616905	99.3413831
		Average (%):	0.208057845	99.79194216

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TABLE XII
COMPARISON OF DATA DELIVERY TIME BETWEEN LCD AND ARDUINO CLOUD ON LIQUID SOAP WATER SOLUTION

Testing	LCD	Arduino Cloud	Delay (Second)
1	15:20:34	15:20:35	1
2	15:22:37	15:22:39	2
3	15:25:01	15:25:02	1
4	15:27:15	15:27:16	1
5	15:28:50	15:28:51	1
6	15:31:34	15:31:35	1
7	15:32:15	15:32:16	1
8	15:35:11	15:35:13	2
9	15:36:44	15:36:46	2
10	15:38:44	15:38:45	1
		Average:	1.3

Table XI shows the pH measurements of liquid soap water solutions. The Smart pH Meter shows readings between 9.12 and 9.17, while the SNI pH meter varies from 9.11-9.17. The accuracy of the Smart pH Meter is very high, with an average of 99.79%, and the average percentage error is only 0.21%. Two tests had very accurate results, with a 100% accuracy rate on the first and ninth tests. Table XII shows the results of the delay between reading on the LCD and sending data to the Arduino Cloud, with an average delay of 1.3 seconds, indicating efficient data transmission.

TABLE XIII
RESULTS OF PH MEASUREMENTS ON LE MINERALE WATER SOLUTION

Testing	Smart pH Meter	pH Meter	Error (%)	Accuracy (%)
1	7.12	7.16	0.558659218	99.44134078
2	7.12	7.17	0.69735007	99.30264993
3	7.21	7.3	1.232876712	98.76712329
4	7.25	7.31	0.820793434	99.17920657
5	7.25	7.26	0.137741047	99.86225895
6	7.12	7.14	0.280112045	99.71988796
7	7.08	7.2	1.666666667	98.33333333
8	7.17	7.2	0.416666667	99.58333333
9	7.21	7.21	0	100
10	6.91	7.19	3.894297636	96.10570236
		Average (%):	0.970516349	99.02948365

TABLE XIV
COMPARISON OF DATA DELIVERY TIME BETWEEN LCD AND ARDUINO CLOUD ON LE MINERALE WATER SOLUTION

Testing	LCD	Arduino Cloud	Delay (Second)
1	12:21:36	12:21:35	1
2	12:23:33	12:23:31	2
3	12:32:52	12:32:51	1
4	12:34:24	12:34:24	0
5	12:36:56	12:36:55	1
6	12:44:10	12:44:09	1
7	12:49:37	12:49:36	1
8	12:51:17	12:51:16	1
9	12:53:15	12:53:14	1
10	12:59:31	12:59:30	1
		Average:	1

Table XIII shows the pH measurement results for the Le Mineral water solution. Smart pH Meter shows that the accuracy

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of the Smart pH Meter remains high, with an average of 99.03% and an average error percentage of 0.97%. There was one very accurate test, with a 100% accuracy rate on the ninth test. Table XIV shows the results of the Delay time between reading on the LCD and sending data to the Arduino Cloud, with an average delay of 1 second, indicating a very efficient and fast data transmission.

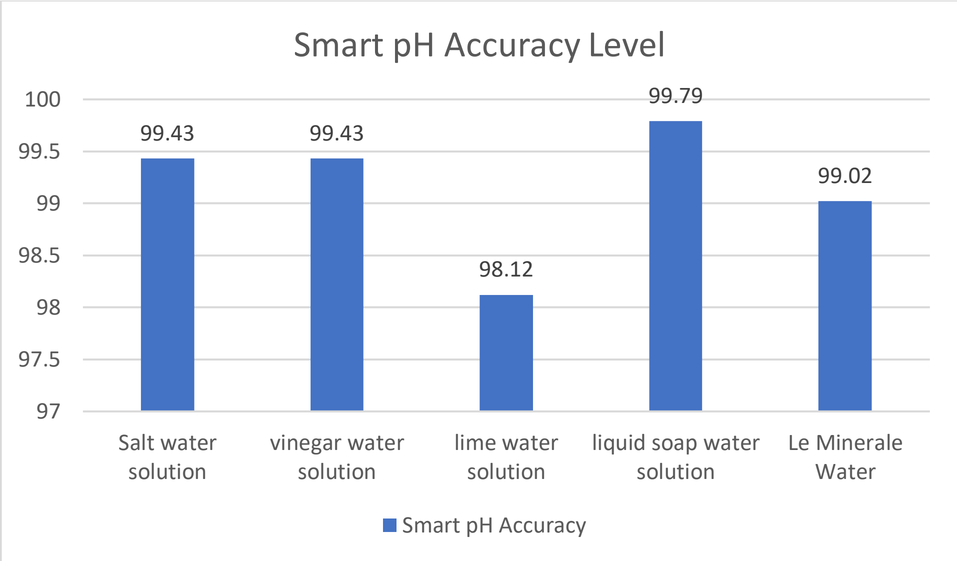

Fig.8. Smart pH Accuracy Level Graph

Fig.8 shows the accuracy of the Smart pH Meter in measuring the pH of various types of water solutions. Liquid Bath Soap Water Solution showed the highest accuracy (99.79%), followed by Salt Water and Sugar Food Water Solutions (both 99.43%), Le Mineral Water (99.02%), and Lime Water Solution (98.12%). Despite the slight variations, the Smart pH Meter performed very well, with accuracy levels above 98% for all types of solutions tested, ranging from acidic (Lime Water) and neutral (Le Mineral Water) to alkaline (Liquid Soap Water). Small differences in accuracy may be due to variations in the chemical properties of each solution. Still, this tool shows consistency and high reliability in measuring the pH of various solutions.

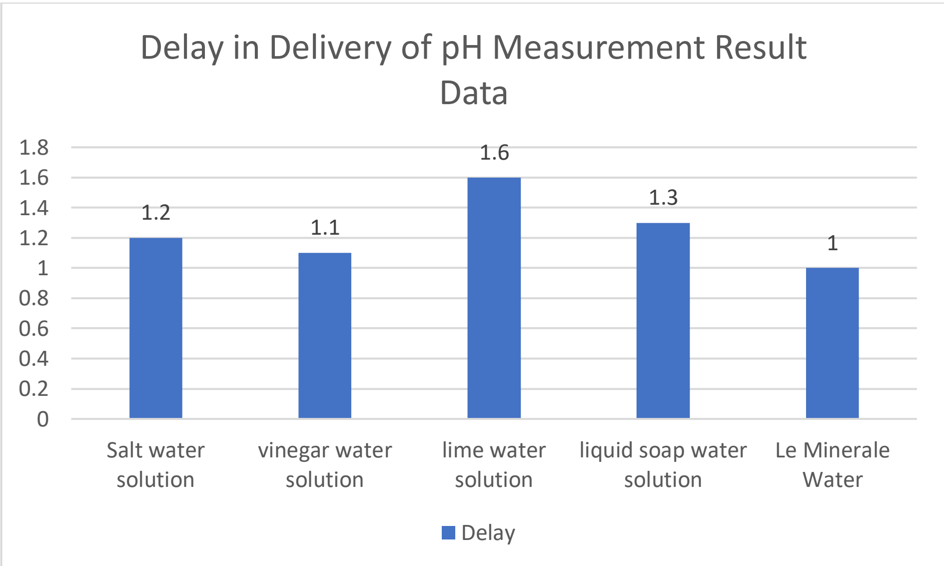

Fig.9. Delay Comparison Graph

Fig.9 shows the average delay (in seconds) between data recording on the LCD and Arduino Cloud for various types of solutions tested using the Smart pH Meter. Lime Water Solution has the highest delay of 1.6 seconds, while Le Minerale Water shows the lowest delay of 1 second. Liquid Bath Soap Water Solution has a delay of 1.3 seconds, Salt Water Solution 1.2 seconds, and Food Sugar Water Solution 1.1 seconds. Although there are slight variations, the delay for all solutions remains relatively low, ranging from 1 to 1.6 seconds. This data transmission system from the Smart pH Meter to the Arduino Cloud works efficiently and consistently for various solutions, with minimal time differences between local measurements and data storage in the cloud.

This excellent data transmission performance is inseparable from the role of FTTH technology integrated into the Smart pH system. FTTH enables high-speed connectivity and low latency, which is very important for real-time data transmission in the context of a smart laboratory. The average delay of 1.2 seconds between recording on the LCD and sending to the Arduino Cloud shows that the FTTH integration successfully provides optimal performance in transmitting pH measurement data.

The combination of the high accuracy of the Smart pH Meter and the data transmission speed supported by FTTH creates a reliable real-time pH measurement system for smart chemical laboratories. This proves that integrating IoT and FTTH technologies can significantly improve the efficiency and reliability of collecting and transmitting pH measurement data, which is crucial in modern chemical research and experiments.

The test results show that Smart pH has an average accuracy rate of 99%, higher than previous studies that only achieved an accuracy of below 98% [11]–[13][15]. In addition, this study tested solutions with acidic, basic, and neutral properties, such as vinegar water, lime, Le Minerale, liquid bath soap, and salt solution. This approach is different from previous studies that only focused on one type of solution [11]–[13][15], making the device less flexible. With more diverse testing, the developed Smart pH has proven reliable for various solutions.

This study also evaluated the delay time in data transmission via the Arduino Cloud application, which recorded an average of only 1 second. This aspect was not explored in previous studies [11]–[15], thus demonstrating the additional advantages of this device in real-time monitoring. The combination of high accuracy, testing on various solutions, and good delay performance make this Smart pH highly recommended for application in future smart chemistry laboratories, especially with the integration of fiber optic networks.

IV. CONCLUSION

The research concludes that the developed Smart pH system, integrating Internet of Things (IoT) and Fiber To The Home (FTTH) technology, has successfully met its objectives and performs satisfactorily for applications in smart chemical laboratories. The system measures the pH value of various solutions in real-time with an accuracy rate exceeding 99%. IoT technology enables automatic data collection, while FTTH integration ensures low-latency data transmission, averaging only 1 second. This performance supports the needs of modern chemical laboratories, with advantages such as higher accuracy (up to 99.79% for certain solutions), reduced data transmission delays (1 to 1.6 seconds), and compliance with the national standard SNI ISO/IEC 17025:2017 for laboratory measurements.

Key findings highlight the Smart pH system's significant improvements over traditional methods, including enhanced data transmission speed and reliability due to the combination of IoT and FTTH. The system is versatile and suitable for teaching and advanced research applications in secondary education. Testing with various solutions shows its flexibility in measuring acidic, neutral, and basic properties. Additionally, the IoT integration with cloud-based monitoring allows for accurate remote tracking, and FTTH technology increases data transmission stability and speed, making it a superior solution to other connectivity methods.

For further development, several recommendations can be made. First, expanding the testing range by using more types of solutions and different concentrations will provide more comprehensive insights into the performance of the Smart pH Meter. Second, the development of automatic calibration features on this device is expected to improve ease of use while increasing measurement accuracy. In addition, implementing long-term tests is important to evaluate the stability and durability of the pH sensor in continuous use, especially in a laboratory environment. Furthermore, integrating the Smart pH system with a more sophisticated data analysis platform will enable real-time and predictive pH trend analysis, providing significant added value for users. A more friendly and responsive user interface must also be developed to improve data accessibility. Finally, exploring the integration of the Smart pH Meter with other laboratory automation systems can be a strategic step to create a more holistic and efficient smart laboratory ecosystem. By implementing these suggestions, it is hoped that Smart pH research can significantly contribute to developing smart chemical laboratories and pave the way for further innovation in this field.

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