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WATER QUALITY MONITORING SYSTEM FOR AQUAPONIC TECHNOLOGY USING THE INTERNET OF THINGS (IoT)

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Abstract: The fishery sector has a vital role in driving Indonesia's economy. However, the supply of fish has recently begun to dwindle because of the high cost of fish and unpredictable weather changes. Because of that, this increases the demand for freshwater fish and raises the potential for freshwater aquaculture. Besides, finding suitable water, sources and farming land for fish is extremely difficult because of the limitations of the primary source. This study aims to develop an Internet of Things (IoT) that can monitor water quality parameters, including acid content, dissolved oxygen, the temperature of the water, as well as ammonia, and is integrated with Internet-based mobile applications. The results of the system design have been successfully implemented. The system structure has successfully incorporated a sensor that collects data from the system and sends it to the blynk cloud server, which can

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be accessed directly via the Internet. Furthermore, this research showed that water quality and circulation are well preserved. The sensor's accuracy of potential hydrogen (pH) acid water is an average error of 1.52%, temperature sensor error of 0.238%, dissolved oxygen sensor error of 0.23%, and ammonia sensor error of 1.723%, and the monitoring system is functioning normally.

Keywords: aquaponic; monitoring of water quality; internet of things.

2020 AMS Subject Classification: 92B05.

1. INTRODUCTION

Indonesia is the largest marine country and has a broad fishery sector that is the driving force of Indonesia's economy because being the civilian's primary livelihood source [1]. Because of that, the fish supply has recently decreased due to high fishing costs and unpredictable weather changes [2]. These problems impacted in reducing fish supply and increasing demand for freshwater fish which influence the potential growth for freshwater aquaculture industry [3]–[5]. This potential is fraught with difficulties, such as the scarcity of land in urban areas, and population growth leads to land clearing, which leads to more land conversion for settlements [6], [7]. This is problematic because limited land cultivation technology and good water quality are required to produce high productivity yield [8], [9].

Based on the described challenges, aquaponics is one solution to land and water constraints that combines hydroponics and a recirculating fish farming system [10]–[14]. Based on theory, aquaponic systems use fish farming waste as plant growth nutrients [15], [16]. As a result, nutrient bacteria act as a natural filter to remove dissolved nitrogen and phosphorus from the plant. Besides, water quality monitoring is a critical item in aquaponics activities because water is a medium that significantly impacts aquatic animals' productivity. Therefore, monitoring is required to maintain water quality [13], [17]–[19]. Referring to a study, the monitoring is still done manually for the time being [20]. This activity is inefficient and time-consuming because cultivators must attend the location to maintain the current state of the cultivation environment. In the precision agriculture 4.0 era, cultivators can monitor remotely and in real-time via the Internet [10], [20]–[23].

To sum up, these explanations motivated us to gain more research to develop an Internet of Things (IoT) monitoring system using the ESP8266 module as a delivery module. Data transmission can be monitored via the mobile application, and notifications can be sent directly based on a predefined threshold.

2. PREVIOUS STUDIES

Aquaponics is a soilless farming method that combines hydroponic plant growth with fish farming in an aquaculture tank [13]. This system pumps ammonia-rich fish waste from aquaculture containers to the hydroponic bottom [13], [24]. The fish waste is converted into organic fertilizer by living bacteria in the bed. This process makes plant roots filter and treats water for fish habitat, which is then recycled back into aquaculture containers [25]. Furthermore, the aquaponic system allows plants and fish to coexist in a symbiotic environment, which promotes agricultural and fisheries sustainability. Water quality parameters in the aquaculture tank and hydroponic bases, such as temperature, dissolved oxygen (DO), pH, electrical conductivity (EC), dissolved solids (DS), and total ammonium nitrate (TAN), are used to ensure the growth and survival of the organisms in the aquaponics system. Furthermore, environmental parameters such as air temperature, relative humidity (RH), carbon dioxide (CO_2), and light must be monitored and automatically controlled regularly [13].

Tyson *et al.* [26] stated that aquaponics has a positive impact because of community concerns over using energy and water in aquaculture. An aquaponic system requires three things: water, energy, and fish feed to produce fish and plant production [27]. Farmers can maintain costs and efficiency throughout the production process by considering the artificial technology concept [28]-[29]. So that in the process, the level of risk in an aquaponic system requires water quality management capabilities to produce a successful business [30].

Numerous water quality monitoring studies have been done in different models related to this research. The first research was conducted by Pu'Ad, Sidek, and Mel [10] used WeMOS to investigate water quality monitoring in aquaponics data was successfully processed using a WeMOS board and the message queuing telemetry transport (MQTT) protocol before being sent to a Raspberry Pi (base station) for storage and visualization. The other research, also proposed by Almetwally, Hassan, and Mourad [21] verified that the system supports the smart city concept, which does not necessitate human interaction and saves money on labor and operations. It also makes effective use of various filters to improve water quality [21], [23]. The subsequent research related to the IoT was pond monitoring, which was integrated into the mobile application [5], and the research was implemented successfully. It primarily incorporates five sensors that measure essential ecological parameters to determine water quality: temperature, pH, DO, total dissolved solids (TDS), and salinity. The other research in a fishpond in water quality monitoring, also conducted by [13], successfully built up the IoT system with several sensors: temperature, pH, DO, turbidity, ammonia, and nitrate sensors.

Furthermore, the following research related to water monitoring quality, conducted by Kurian, Saji, Joseph, and Kuriakose [24], developed an automated system for monitoring water quality for aquaponics. The research used several sensors for monitoring that monitor pH, temperature, ammonia, and nitrate level. The developed system has successfully assisted farmers in reducing manual effort while maintaining a balanced system wherein fish, plants, and microbes are in the same equilibrium interaction. The other research, done by Khaoula, Abdelouahid, Ezzahoui, and Marzak [31], constructed a monitoring and control architecture for a solar-powered IoT-based aquaculture system. The system could control water quality by utilizing environmental factors such as water depth, water temperature, EC, CO_2, and TAN [31]. Previous studies on monitoring of water quality proposed by Taha et al. [32], researched a comprehensive overview: of advanced innovative systems and IoT for aquaponics automation. The research has mentioned that the IoT system's opportunity and potential in the water quality monitoring system's innovative control units tend to benefit users and make them more sophisticated in technology [32].

3. MATERIALS AND METHODS

The research data used is water quality parameter data collected using sensors. pH, temperature, DO, and ammonia sensors. The sensor's output is numerical data shown in Tables 3 - 6. In addition to this research, we constructed a natural environmental aquaponics system with the plants used in aquaponics such as water spinach, and tilapia fish to support the environment of the aquaponic system. Besides, the threshold value used for the notification is the ideal threshold value of kale and tilapia, and the aquaponics consists of one node. The last is that the mobile application can only be run on the Android operating system, at least version 4.0 (Ice Cream Sandwich).

3.1. Software and Hardware for IoT System. Table 1 and Table 2 detail the devices used in this research, including hardware and software.

TABLE 1. Hardware

Hardware	Detail of Specification
Microcontroller	Arduino Mega 2560 R3
pH sensor	pH-4502C
Temperature sensor	DS18B20
DO Sensor	Gravity: Analog DO Sensor
Ammonia sensor	MQ-135
Wi-Fi	ESP8266
Jumper Cable	20 cm, and 10 cm (male-female, female-female, male-male)
Personal Computer / Laptop	Axioo MyBook Intel N3350, RAM 3GB
Manual pH test kit	KL-009(I)
Manual Temperature test kit	Lutron PDO-520
Manual DO test kit	Lutron PDO-520
Manual Ammonia test kit	Tetra NH3/NH4

TABLE 2. Software

Software	Detail of Specification
Arduino IDE	Version 1.8.7.0
BLYNK	Application servers and databases

3.2. Flowchart Research. This study's flowchart begins with problem identification, followed by a literature review, system architecture design, program implementation, integration, testing, and evaluation. Figure 1 shows the flowchart for this study.

3.3. Design of Water Quality Monitoring. The program implementation aims to determine the programming language used to compile the program and perform hardware assembly. The microcontroller used to upload the compiled program. On the other hand, this process included developing the mobile application user interface. Figure 2 shows the design details for monitoring water quality.

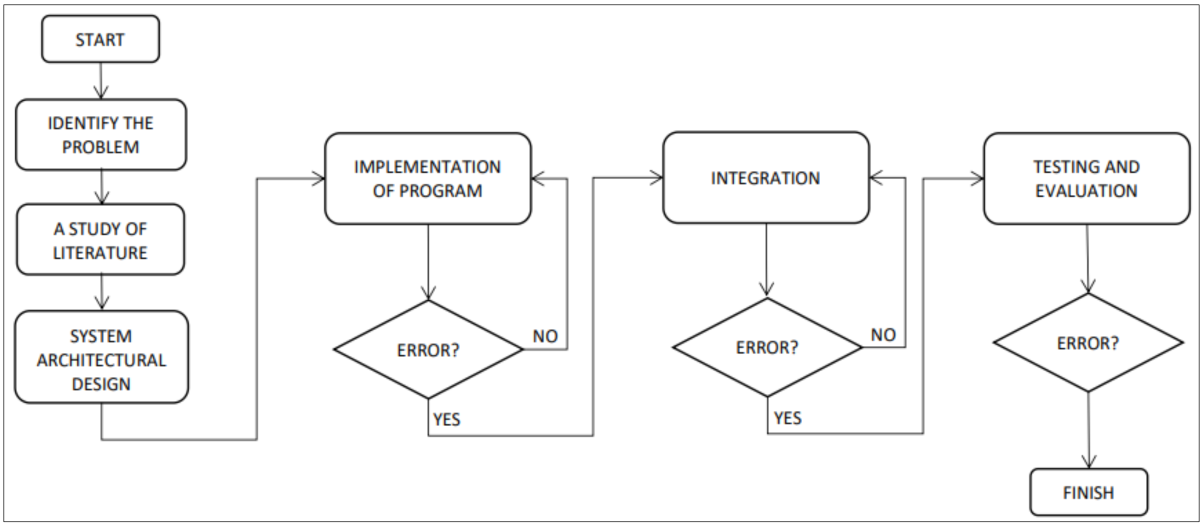


FIGURE 1. Flowchart of Research

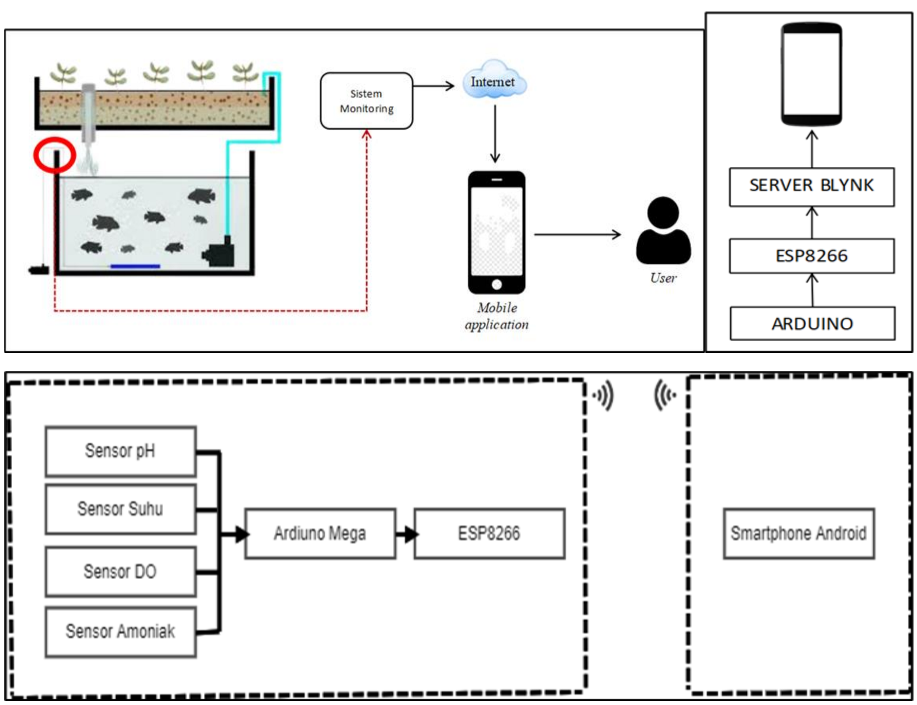


FIGURE 2. Design of Water Quality Monitoring

The scenarios of the water quality monitoring started from monitoring the aquaponic system that monitored temperature, pH, DO, and Ammonia that connected via mobile application and saved on the cloud-based system (server BLYNK). The data from the monitoring were displayed on the mobile in the next section. Furthermore, the following process was that data from the aquaponics were transmitted via the Arduino with the ESP8266's module. The data collected from the server were used to analyze the water quality discussed in the following water quality evaluation section.

3.4. Integration System. The integrated system is intended to integrate the compiled hardware and the mobile application interface. In this step, the main point to be considered in this process is using libraries that must follow the system's requirements that were built before. Also, the code program code size must be compatible with the microcontroller's capacity.

3.5. Testing and Evaluation. There are three processes in the testing and evaluation process. These are calibration testing, functional testing, and monitoring testing. A calibration test is the first step in validating a tool created with calibrated laboratory equipment. Functional tests are performed to determine the monitoring system's performance, from the hardware to the notification system, and whether it is functional. Moreover, the monitoring testing maintains whether the mobile application monitoring process can run functionally. Those are data visualization and are displayed directly on the mobile interface system.

4. Result and Discussion

4.1. Integrated System of Water Quality Monitoring based on IoT. The system of monitoring water quality based on the IoT has been successfully developed in this research. The aquaponics system has been built and runs functionally and adequately as shown in Figure 3. Furthermore, Figure 4 has also been completed arranging all the components and circuits. The prototype sensors' design in the aquaponic system parameters was also successfully assembled. The design prototype of the sensors is shown completely in Table 3.

FIGURE 3. Aquaponics Integrated System

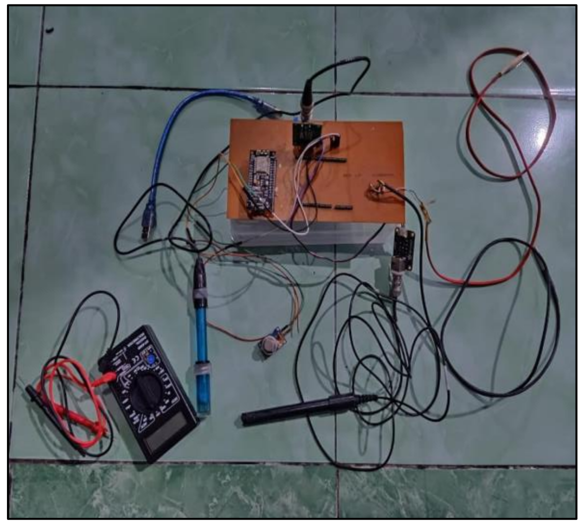
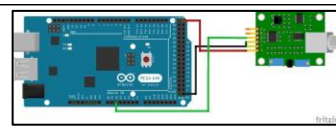
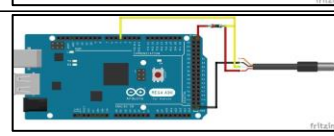
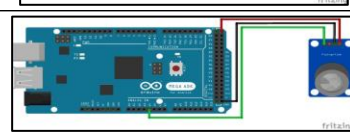
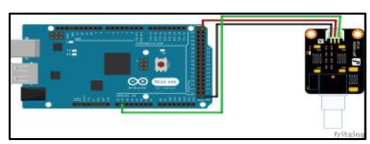
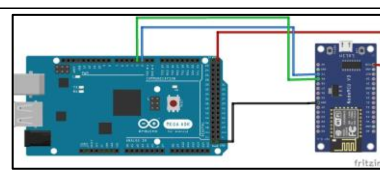


FIGURE 4. Entire Circuits

TABLE 3. Prototype Sensors

Prototypes of Sensors	Figure
Prototype of pH sensors	
Prototype of temperature sensor	
Prototype of ammonia sensor	
Prototype of DO	
Prototype of ESP8266	

4.2. Calibration Testing Evaluation. Test results from sensors and laboratory equipment that have been standardized are depicted in Tables 4 - 7. The comparison test results between sensors and lab equipment revealed the tool's sensitivity to the environment. Meanwhile, the sensor tolerance limits were tested using standard lab equipment using regression tests. In addition, to evaluate the calibration test function, the equations for each function: pH, temperature, DO, and ammonia in are shown in Table 8.

TABLE 4. Result Test of Calibration pH Sensor

Sensors	Lab Equipment	Calibration Results	Error (%)
3.28	5.92	5.77	0.44
4.53	6.02	6.35	0.24
5.67	7.34	7.29	0.22
6.43	7.89	7.92	0.18
7.69	8.47	8.96	0.09
8.32	9.68	9.48	0.14
9.68	10.35	10.61	0.06
10.51	11.09	11.29	0.05
11.98	12.56	12.51	0.04
12.94	13.31	13.29	0.02
13.46	14.13	13.73	0.04

TABLE 5. Result Test of the Calibration Temperature Sensor

Sensors	Lab Equipment	Calibration Results	Error (%)
21.3	22.8	22.2	0.066
23.6	24.1	24.5	0.020
25.1	25.7	25.9	0.023
25.9	26.3	26.6	0.015
26.8	27.6	27.5	0.029
27.7	28.5	28.3	0.028
29.2	29.6	29.7	0.013
29.8	30.4	30.3	0.019
30.9	31.7	31.4	0.025

TABLE 6. Result Test of Calibration DO Sensor

Sensors	Lab Equipment	Calibration Results	Error (%)
4.6	4.8	5.0	0.04
4.9	5.5	5.2	0.10
5.9	6.0	6.0	0.01
6.1	6.3	6.2	0.03
6.5	6.7	6.5	0.02
7.0	6.8	6.9	0.03

TABLE 7. Results Test of Calibration Ammonia Sensor

Sensors	Lab Equipment	Calibration Results	Error (%)
0.0001	0.0002	0.00032	0.500
0.0003	0.0005	0.00052	0.400
0.0005	0.0009	0.00072	0.440
0.0007	0.0010	0.00091	0.300
0.0011	0.0012	0.00130	0.083

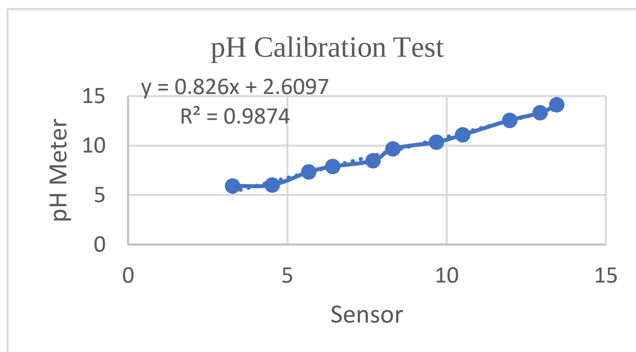
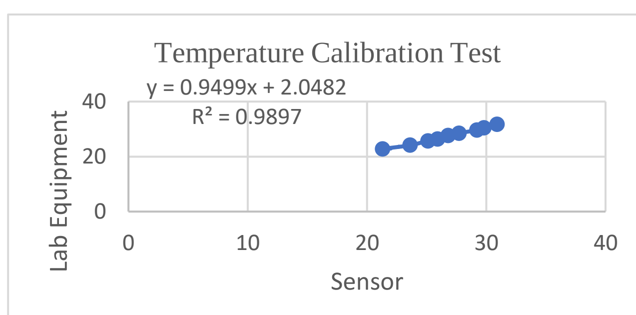
TABLE 8. Equation of calibration test

Equation Calibration	Formula
Equation of pH calibration	y = 0,993243243x + 0.000223649 (1)
Equation of temperature calibration	y = 0.9499x + 2.0482 (2)
Equation of DO calibration	y= 0.8019x + 1.3391 (3)
Equation of ammonia calibration	y = 0.9932x + 0.0002 (4)

Based on Tables 4-7, the calibration test showed that the pH sensor has an error value of less than 0.05. The calibration results were similar to the value taken using laboratory equipment. These results indicated that the pH, temperature, DO, and ammonia sensors could be used properly [17], [32]. The result of the calibration parameter sensors was calculated using Equation 1 to equation 4 in Table 8. In addition, the calculation results of the calibration parameters are shown in Table 9.

4.3. Water Quality Evaluation. Furthermore, this research evaluated water quality by measuring quality parameters: pH, temperature, ammonia, and DO. The curves of the average fluctuation of each parameter in the aquaponics system during the research observation time were presented. The measurement results of the water quality are shown in Table 9.

TABLE 9. Curve of Calibration Tests

Types of Calibrations	The curve of Calibration Tests
Calibration of pH sensor	
Calibration of Temperature sensor	

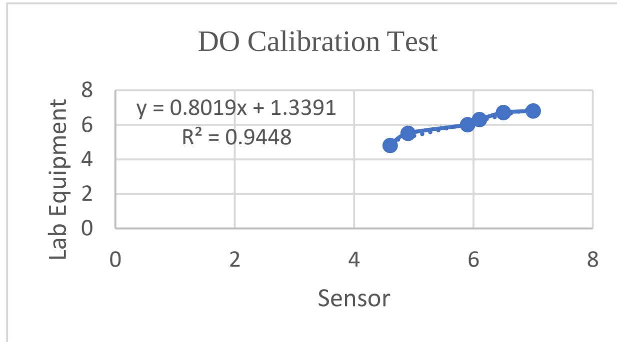
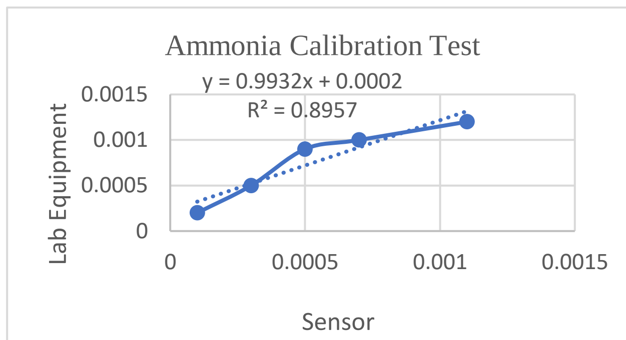
<table>
<tr><td>Calibration of DO sensor</td><td>
</td></tr>
<tr><td>Calibration of ammonia sensor</td><td>
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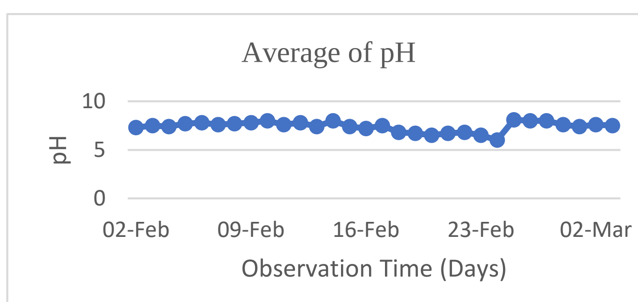
TABLE 10. The Curve of Water Quality Evaluations

<table>
<tr><th>Type of Parameters</th><th>The Curve of Parameters Quality</th></tr>
<tr><td>Average of pH</td><td>
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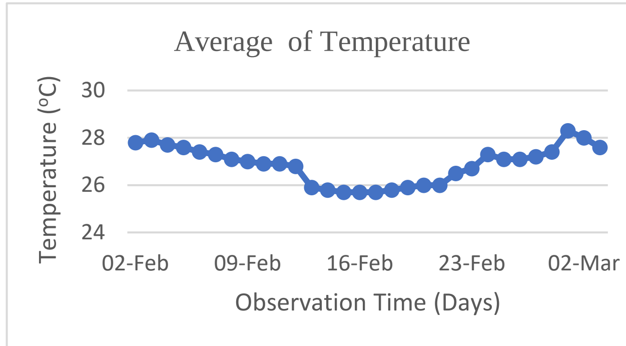
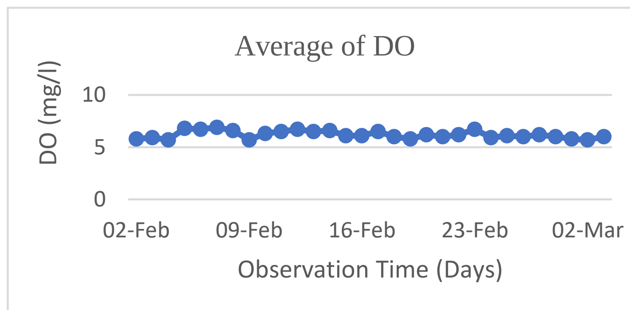
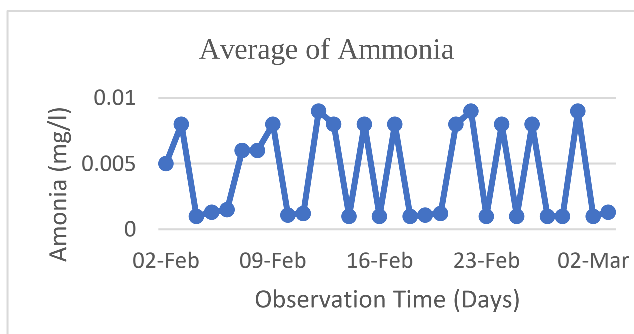
Average of temperature	
Average of DO sensor	
Average ammonia	

Refers to the results of observations of pH during the observation time (Table 10), the pH results have a value of 6.5 - 8.1. These results agreed with the previous research [16], [33], [34] that a suitable pH for nitrification, tilapia cultivation, and hydroponic systems was 6 - 9 [16], [35]. Fluctuations in the pH are due to the relationship with DO, which is the pH of the water is influenced by DO. Where the less DO, the tendency of the pH will be alkaline, and the opposite condition is if there is DO in large quantities, it will be more acidic [16], [36]. In line with the results of this research, the relatively stable DO concentration in aquaponic ponds resulted in a relatively stable pH. Same as the temperature parameter value was 25.7-28.3 ◦C, and these results are also the same as other research [16], [37], [38]. The ideal temperature for tilapia cultivation was 25-30 ◦C, and the results of this study were optimal for the growth of tilapia in aquaponic ponds.

Moreover, the results of DO parameter observations during the research time show that the value of DO was 5.7-6.8 mg/l. The results that we obtained are also the same and approved by [16], [35], that mentioned the DO is suitable for the nitrification process, tilapia cultivation, and hydroponic systems with a value considerable more than three (>3). Fluctuations in DO values occur due to the influence of dissolved particles in water [5], [13]. The last parameter was ammonia. The ammonia observations during the research time showed that the ammonia value was 0.0013-0.001 mg/l. These results followed the research from other studies [16], [35], [39], that good ammonia for aquaponic aquaculture is less than one (<1). Ammonia values fluctuate due to the conversion of ammonia to nitrate, which is influenced by oxygen solubility [35]. This result was also related to the rate of ammonia to nitrate conversion. Based on the research conducted by Amin, Musdalifah, and Ali [40], stated that the aquaponic system could significantly increase the rate of ammonia to nitrate conversion, where converting to nitrate occurs optimally under stable DO conditions [26], [41], [42].

5. CONCLUSION

This research has successfully developed a system for water quality monitoring based on the IoT concept. We used an android-based mobile application for IoT implementation with the specification ice-cream sandwich for aquaponic cultivation monitoring. The research has been successfully implemented in tilapia's aquaponic cultivation, the same as the natural habitat. Results show that all the sensors were functioning correctly, and the range of the values collected was precisely the same, as proven by several related research studies. In addition, the ESP8266 module that sent data from Arduino to Blynk also worked properly. The data is retrieved from blynk for the mobile app's alert notification process, which runs every fifteen minutes.

CONFLICT OF INTERESTS

The author(s) declare that there is no conflict of interests.

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