Design and Control System of Acidity Degree and Dissolved Oxygen Levels in Aquaponic Systems

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Abstract. The inhibiting factors for plant and fish growth in aquaponics systems are farmers who never control and monitor the quality of Dissolved Oxygen (DO) levels and the degree of acidity/Power of Hydrogen (pH) of water properly. Uncontrolled and monitoring of the quality of pH and DO in water properly and periodically will have an impact on the process of nitrification and denitrification of the aquaponics system. Therefore, it is necessary to update the technology on the aquaponic to automatically maintain the DO and pH parameter to balance the ecosystem. To design a control system, a series of validations are carried out on the sensors used. The MSP340 pH sensor has an average error of 2.58% and an accuracy of 97.42%. The DO sensor SEN0237-A has an average error of 4.82% and an accuracy of 95.18%. The ultrasonic sensor has an average error of 3.14% and an accuracy of 96.86%. Based on the comparison of parameter values before and after the control system was installed, the pH value was still in the neutral pH range (6.5–8.5). While the DO value tends to be below the predetermined setpoint (1–5 mg/l). Based on the comparison of growth rates, it was found that the average plant growth rate decreased from 13.4% to 12.5% during the two weeks of the study. However, the length of the plant increases to 0.2 cm. The fish growth rate increased in the first week using a control system up to 17%, survival rate reached 100% in the second week **.**

Keywords: Acidity Degree; Dissolved Oxygen · Aquaponics · Control System

1 Introduction

Based on research from [1], the inhibiting factor in the growth of plants and fish in aquaponics systems is that farmers never control and monitor water quality properly. Water quality parameters that have a significant influence on the survival of fish are dissolved oxygen (DO) and acidity (Ph) [2]. Uncontrolled and monitored quality of DO and water Ph properly and periodically will have an impact on the nitrification and denitrification process of aquaponic systems [3], thus disrupting the balance of water ecosystems and decreasing biota populations [4].

N. I. Inda et al. (Eds.): ISST 2022, APR 7, pp. 192–207, 2023.
https://doi.org/10.2991/978-94-6463-228-6_22

Table 1. Aquaponic Plant Specification

Specification	Size
Plant pond	0,5 m × 0,5 m × 0,5 m
Growing media	0,02 m × 0,02 m × 0,01 m
Growing media hole diameter	0,1 m

According to research from [1], although Ph is not directly related to DO, the presence of DO has a close relationship with the process of respiration and photosynthesis, both of which require and produce carbon dioxide compounds (CO2) and will directly affect the Ph of water [5]. Therefore, a technological update is needed on the aquaponic control system that can automatically maintain the DO and Ph parameter values to balance the ecosystem and increase the growth rate of plants and fish. By designing a technology prototype for the control system for dissolved oxygen (DO) and acidity (Ph) levels in the aquaponics system, it is hoped that it can fulfill the research objective of maintaining the stability of DO and Ph values that can affect the growth rate of fish and plants.

2 Material and Methods

2.1 Hardware Design

The hardware design consists of designing an aquaponic system plant using SketchUp 2020 software and designing electronic components using the Fritzing application. Table 1 shows the specifications of aquaponics plant.

2.2 Control System Design

The design of the control system in the form of a Closed Loop Control System block diagram can be seen in Fig.

In Fig. 1, there is a detailed design of the components that make up the control system that will be used in the plant. The controller used is the Arduino Mega 2560 microcontroller. The actuators used are DC pumps and aerators, and the sensors used are the MSP340, DO Sensor SEN0237-A, and the HY-SRF05 Ultrasonic Sensor.

2.3 Software Design

The software design aims to design the command code on the controller and visualize the results of the integration between several sensors and actuators. When designing software, the first step is to write microcontroller code for sensor and actuator integration using Arduino IDE [7].

After all the code has been uploaded properly, the microcontroller will process the measurement data from the DO, pH, and Ultrasonic sensors simultaneously and will

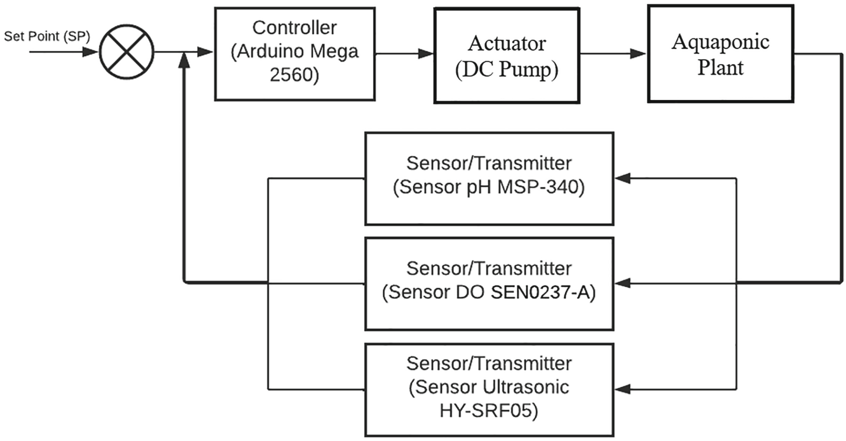

Fig. 1. The block diagram of the Closed Loop Control System [6]

determine whether the pH, DO, and Ultrasonic values are following the predetermined setpoint. When the measurement value on the sensor is appropriate, then the next step is to display the measurement data on the screen. However, if the parameter value does not match the setpoint, the controller will initiate the actuator to stabilize the parameter value until it matches the setpoint.

2.4 Initial Data Collection

Initial data collection on pond water quality is carried out when the control system has not been installed. Parameter values collected were DO value, pH, and water level in aquaponic fish ponds for 14 days after planting and stocking tilapia seeds [8]. In the initial data collection process for kangkong, the data observed and measured were the growth rate and plant length. In the initial data collection process on tilapia, the data observed and measured was the growth rate of the fish and its survival rate [9]. Both data will be measured every day at the same time.

2.5 Hardware and Software Integration

The tool starts to work when the system reads the level, pH, and DO parameters at the same time. The aquaponic pool level has a setpoint of 0.4 m. When the pool water level exceeds the setpoint, the level pump will automatically turn on and remove excess water until the level value matches the setpoint. Determination of the setpoint at 0.4 m aims to anticipate the increase in levels when there is rain and the treatment in adding liquid pH Up and pH Down.

The pH setpoint values were adjusted according to the neutral standard, with a pH of 6.5 to 8.5 [10]. If the pH of the pool water exceeds 8.5, the pump will pump the pH Down fertilizer liquid in the form of Potassium Hydroxide. If the pH of the pool water is less than 6.5, the pump will pump pH Up fertilizer in the form of Phosphoric Acid to stabilize the pH. The DO setpoint value is set according to the standard, which is 5 mg/L

[11]. If the DO in the water is less than 5 mg/l, the aerator will help circulate oxygen until the DO value matches the setpoint.

2.6 Aquaponic Control System Test

After the integration of hardware and software, the next step is testing all elements of the aquaponics system performance. Some of the elements that will be tested are DO sensors, pH sensors, level sensors, DC pumps, and aerators as actuators in the aquaponics system. All sensors will be validated in the form of percent error and accuracy by comparing their readings using a calibrated measuring instrument. As for the actuator, the tests carried out are performance tests and dynamic response tests [12]. This test aims to determine whether the pump and aerator can run according to the logic test that has been designed on the microcontroller.

2.7 Final Data Collection

Final data collection on pond water quality is carried out after the control system has been installed. The collected parameter values are the trendline of DO value, pH, and water level in aquaponic fish ponds with a span of 14 days after planting and stocking tilapia seeds. In the initial data collection process on kangkong, the data observed and measured were the growth rate and plant length. In the initial data collection process on tilapia, the data observed and measured was the growth rate of the fish and its survival rate. Both data will be measured every day at the same time.

2.8 Data Analysis

Final data collection on pond water quality is carried out after the control system has been installed. After the initial and final data have been collected, the next step is to analyze the data that has been obtained, such as calculating the performance of the sensors used, and comparative studies between plant and fish growth rates based on initial data collection (without using a control system) and final data (using a control system). All data that has been analyzed will be visualized in the form of a graph.

3 Results and Discussion

3.1 The Manufacturing of Aquaponic System Plant

Figure 2 shows an overview of making a fully assembled aquaponic system plant with a front-view visualization.

3.2 The Manufacturing of Aquaponic System Plant

The sensor validation test includes sampling the pH, DO, and Ultrasonic sensor readings which will be compared with calibrated measuring instruments. Tests are carried out to determine the percent accuracy and error in sensor readings and ensure each sensor can read and measure according to the design. A sensor validation test is carried out before all components are integrated.

Fig. 2. Aquaponic system plant

MSP340 pH Sensor. The test was carried out by comparing the results of the MSP340 pH sensor readings with the Lutron WA-2017SD pH Meter. Validation on the MSP340 pH sensor used 11 types of sample solutions, three acidic solutions (pH 3–5), three neutral solutions (pH 6–8), and five alkaline solutions (pH 9–11).

The MSP340 pH sensor before being integrated had an average percent error of 2.58% and a percent accuracy of 97.42%. Figure 3 is a visualization of a bar chart related to the accuracy of the readings between the pH sample read by the MSP340 pH sensor and the pH meter. Based on the percent error obtained, the value of the validation reading between the MSP340 sensor and the pH meter is found to be less than the percent error tolerance that has been set (±5%) [13], so the MSP340 pH sensor can be used in system integration.

HY-SRF05 Ultrasonic Sensor. The test was carried out by comparing the results of the HY-SRF05 Ultrasonic sensor readings with the validation on the HY-SRF05 Ultrasonic

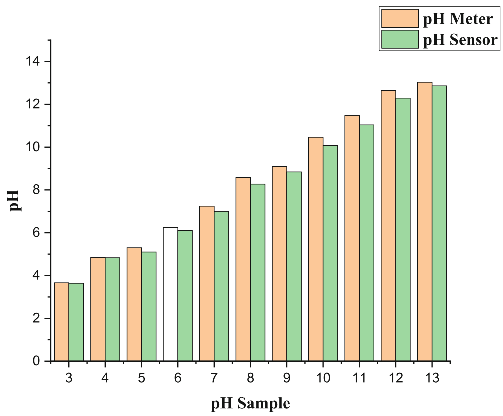

Fig. 3. pH Sensor validation chart with pH Meter before system integration.

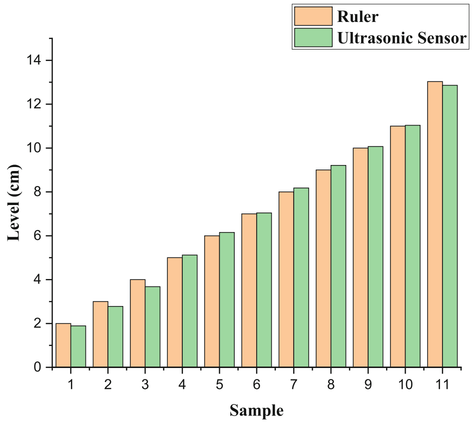

Fig. 4. Ultrasonic Sensor validation chart with Ruler before system integration

sensor using eleven samples at a distance of 2 to 11 cm. Figure 4 shows a bar chart of the ultrasonic sensor validation test results.

The HY-SRF05 Ultrasonic Sensor before being integrated had an average percent error of 3.14% and a percent accuracy of 96.86%. Figure 4 is a bar chart visualization related to the accuracy of the readings between the distance sample values read by the HY-SRF05 Ultrasonic sensor with a ruler. Based on the percent error value obtained, the validation value of the reading between the HY-SRF05 Ultrasonic sensor and the ruler is found to be less than the specified error percent tolerance (±5%), so the HY-SRF05 Ultrasonic sensor can be used in system integration.

SEN0237-A Dissolved Oxygen Sensor. The test was carried out by comparing the results of the SEN0237-A Dissolved Oxygen sensor readings with the WA-2017SD DO meter Lutron. Validation on the SEN0237-A Dissolved Oxygen sensor was carried out at three different times, in the morning (08:00–09:00), in the afternoon (14:00–15:00), and evening (20.00–21.00).

The DO sensor SEN0237-A before being integrated had an average percent error of 4.82% and a percent accuracy of 95.18%. Figure 5 shows a visualization in the form of a bar chart of the accuracy of readings between the sample values read by the DO SEN0237-A sensor and DO Meter. Based on the percent error obtained, the value of the validation reading between the DO sensor SEN0237-A and the DO meter is less than the percent error tolerance set (±5%), so the DO sensor can be used in system integration.

3.3 System Integration

System integration includes a collection of validation data for readings on the MSP340, SEN0237-A Dissolved Oxygen sensor, and the HY-SRF05 Ultrasonic sensor with standard measuring instruments, which aims to determine the percent error value and percent accuracy in reading parameter values by the sensor used when the entire system running at the same time.

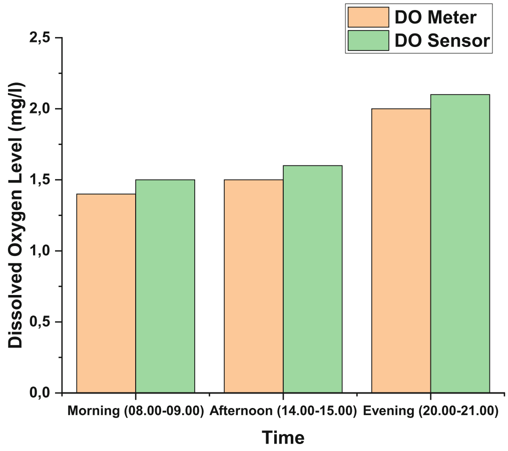

Fig. 5. DO Sensor validation chart with DO Meter before system integration

3.4 The Validation Data Results of MSP340 pH Sensor

The test was carried out by comparing the results of the MSP340 pH sensor readings with the Lutron WA-2017SD pH Meter. Validation on the MSP340 pH sensor uses three types of sample solutions, acidic solution (pH 2.35), neutral solution (pH 7.52), and alkaline solution (pH 12.15).

The MSP340 pH sensor after being integrated has an average percent error of 30.25% and a percent accuracy of 69.75%. Figure 6 is a bar chart visualization related to the accuracy of the readings between the pH sample read by the MSP340 pH sensor and the pH meter. Based on the percent error value obtained, the value of the validation

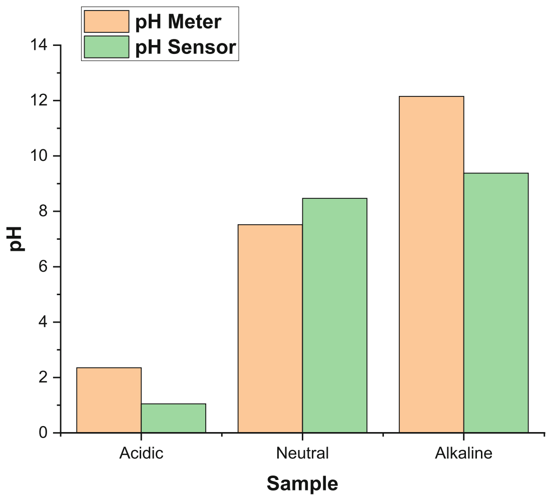

Fig. 6. pH Sensor validation chart with pH meter after system integration.

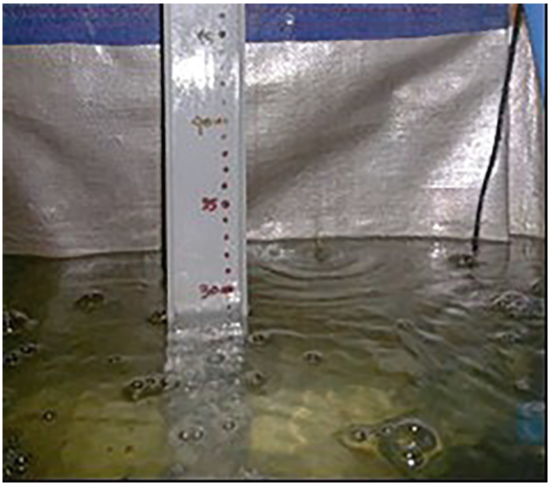

Fig. 7. HY-SRF05 Ultrasonic Sensor Validation Process after System Integration

reading between the MSP340 sensor and the pH meter was found to be more than the specified error percent tolerance (±5%), so the MSP340 pH sensor could not be used in the actuator performance test due to inaccurate and stable readings. Periodic calibration of the sensor, in terms of the type of pH sensor used, including probes and analog sensors, needs to be done to reduce the percent error and increase the percent accuracy of the sensor.

3.5 The Validation Data Results of HY-SRF05 Ultrasonic Sensor

The test is carried out by comparing the readings of the HY-SRF05 Ultrasonic sensor with a ruler as shown in Fig. 7. Validation on the Ultrasonic sensor uses ten samples at a distance of 7 to 16 cm.

The HY-SRF05 Ultrasonic Sensor after being integrated has an average percent error of 0.59% and a percent accuracy of 99.41%. Figure 8 is a visualization in the form of a bar chart related to the accuracy of readings between the distance sample values read by the HY-SRF05 Ultrasonic sensor and a ruler. Based on the percent error value obtained, the validation value of the reading between the HY-SRF05 Ultrasonic sensor and the ruler is less than the specified error percent tolerance (±5%), so it can be concluded that the HY-SRF05 Ultrasonic sensor can be used in level control system performance tests.

3.6 The Validation Data Results of SEN0237-A Dissolved Oxygen Sensor

The test was carried out by comparing the results of the Dissolved Oxygen sensor readings SEN0237-A with the DO meter Lutron WA-2017SD. Validation on the Dissolved Oxygen sensor SEN0237-A using three samples at different times, in the morning (08:00–09:00), afternoon (14:00–15:00), and evening (20:00–21:00).

The SEN0237-A Dissolved Oxygen Sensor after being integrated has an average percent error of 25.38% and a percent accuracy of 74.62%. Figure 9 is a visualization

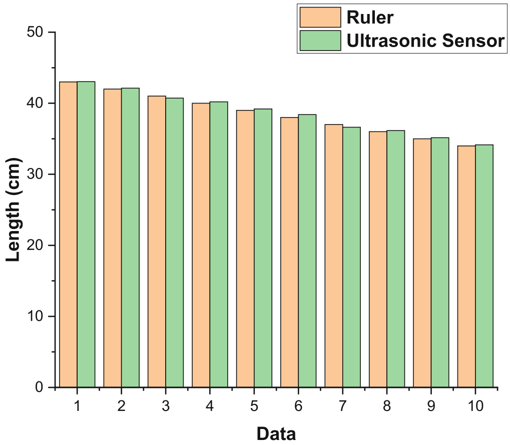

Fig. 8. HY-SRF05 Ultrasonic Sensor Validation Results after System Integration

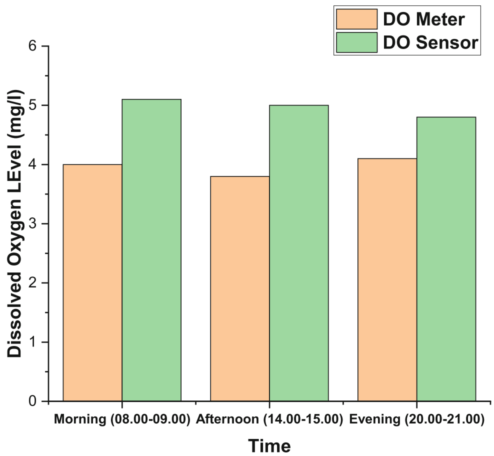

Fig. 9. DO Sensor Validation Chart with DO Meter after System Integration

in the form of a bar chart related to the accuracy of the reading between the dissolved oxygen sample value read by the SEN0237-A DO sensor and the DO Meter. Based on the percent error value obtained, the validation of the readings between the DO SEN0237-A sensor and the DO meter was found to be more than the specified error percent tolerance (±5%), so it can be concluded that the SEN0237-A DO sensor cannot be used in the actuator performance test because inaccurate and unstable readings. Periodic calibration of the sensor, in terms of the type of DO sensor used in the probe and analog, needs to be done to reduce the percent error and increase the percent accuracy of the sensor.

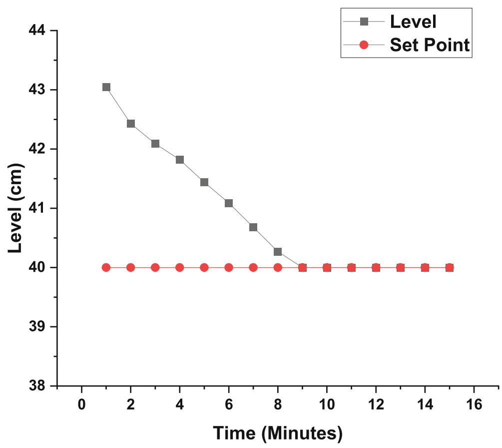

Fig. 10. Dynamic Response of Levels to Time

3.7 Disturbance Test

A disturbance test is a performance test on the plant when the parameter value is changed not according to the setpoint [14]. Performance tests on plants are carried out on parameters that can be read properly and accurately, such as level parameters. The activity carried out to test the performance at the plant level is to increase the level value beyond its setpoint. The following are the results of the disturbance test at the setpoint level when the level is set to 43 cm for 15 min.

Based on the results of the disturbance test in Fig. 10, it can be seen that it takes 9 min to reduce the water level from 43 cm to 40 cm or as much as 7.5 L of water.

3.8 The Trendline of pH and DO Value

Figure 11 and Fig. 12 is the trendline data for pH and DO values every day. Trendline data serves to monitor pH and DO values when the control system is running. Trendline data collection was taken in the morning (08.00–09.00), afternoon (14.00–15.00), and evening (19.00–20.00) and measured using the MSP340 pH sensor and SEN0237-A DO sensor. Based on the trendline of daily pH values in Fig. 11 and 12, it can be seen that the measurement values when using the control system in the morning are in the neutral range (setpoint 6.5–8.5). Meanwhile, DO is below the predetermined setpoint (DO > 5 mg/l). The way to increase DO until it reaches the setpoint is by turning on the aerator actuator.

3.9 Plant Growth Rate

The value of the growth rate of kangkong in the aquaponics system was taken twice, before and after the installation of the control system. The data taken are the value of growth rate and absolute length. Data collection was taken in the morning (09.00–10.00) every day for fourteen days. Table 2 shows data on the growth rate of kangkong

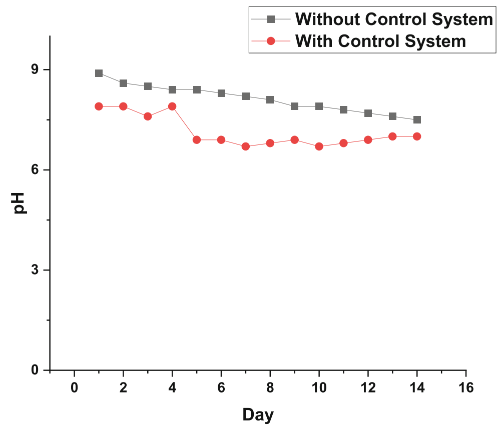

Fig. 11. pH Trendline pH Trendline.

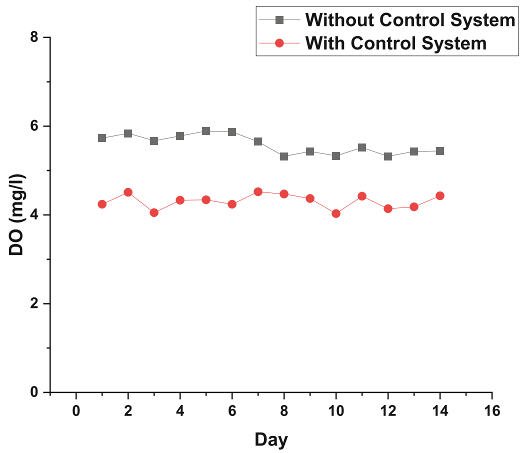

Fig. 12. DO Trendline

for fourteen days in an aquaponic system without a control system. Initial data collection was carried out in ten pots.

Based on Table 2, the growth rate value of kangkong without a control system during the first seven days of the study was 14.3% with an average absolute length of 0.6 cm per day. During the second week of the study, it was found that the value of the growth rate of kangkong decreased to 12.5% with an average absolute length of 0.4 cm.

Based on Table 3, the growth rate of kangkong with a control system during the first seven days of the study was 14.3% with an average absolute length of 0.6 cm per day. During the second week of the study, it was found that the value of the growth rate of kangkong decreased by 10.9% with an average absolute length of 0.7 cm.

Based on the data in Tables 2 and 3, there was a decrease in the rate of plant growth during the two weeks of the study. This happened because three pots had poor seed

Table 2. Plant Growth Rate Data Before Control System Installation

Plant Growth Rate (GR)						
Day	Initial Weight Average (gr)	Final Weight Average (gr)	Initial Length Average (cm)	Final Length Average (cm)	% Growth Rate	Absolute Length (cm)
1	0,0	5,0	0,0	0,0	14,3	0,0
2			0,0	0,5		0,5
3			0,5	1,2		0,7
4			1,2	1,9		0,8
5			1,9	2,5		0,6
6			2,5	3,3		0,8
7			3,3	3,9		0,6
8	5,0	40,0	3,9	4,4	12,5	0,6
9			4,4	5,0		0,5
10			5,0	5,6		0,7
11			5,6	5,9		0,3
12			5,9	6,3		0,4
13			6,3	6,7		0,4
14			6,7	6,9		0,2
Average					13,4	0,5

quality, so they could not grow normally. Abnormal plant growth can also occur due to improper placement of kangkong seeds on rockwool as a planting medium in aquaponics systems.

Although there was a decrease in the growth rate in the aquaponic system, the plants using the control system were higher than the plants without the control system (Fig. 13).

3.10 Fish Growth Rate

Initial data collection was carried out by measuring the weight of three tilapia and counting the number of fish that were still alive every week.

Based on the three fish samples taken in Table 4, it was found that the average initial weight of fish in the first week, the first day was 6 g, and on the seventh day was 8.6 g so the growth rate value was 6.2% per day for 7 days. The number of fish in the first week was 51 fish, but at the end of the week, there were only 34 fish left. The number of fish deaths is potentially caused by fish that are stressed and less adapted to the new environment. Based on the number of living fish, the fish survival rate was 67%. Based on the three fish samples taken, the average weight of the fish in the second week, the

Table 3. Plant Growth Rate Data After Control System Installation

Plant Growth Rate (GR)						
Day	Initial Weight Average (gr)	Final Weight Average (gr)	Initial Length Average (cm)	Final Length Average (cm)	%Growth Rate	Absolute Length (cm)
1	0,0	5,0	0,0	0,0	14,3	0,0
2			0,0	0,5		0,5
3			0,5	1,1		0,6
4			1,1	1,9		0,8
5			1,9	3,0		1,1
6			3,0	3,8		0,9
7			3,8	4,3		0,5
8	5,0	20,0	4,3	4,9	10,7	0,6
9			4,9	5,5		0,5
10			5,5	6,0		0,6
11			6,0	6,7		0,6
12			6,7	7,6		0,9
13			7,6	9,3		1,7
14			9,3	9,5		0,2
Average					12,5	0,7

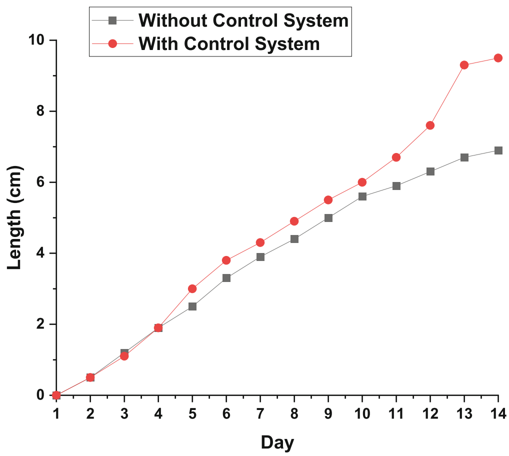

Fig. 13. Plant Growth Length

Table 4. The Data of Fish Growth Rate Before Control System Installation

Week	Initial Weight Average (gr)	Final Weight Average (gr)	%Growth Rate	Initial Fish Number	Final Fish Number	%Survival Rate
1	6,0	8,6	6,2	51	34	67
2	8,6	12,0	5,6	34	28	82

Table 5. The Data of Fish Growth Rate After Control System Installation

Week	Initial Weight Average (gr)	Final Weight Average (gr)	%Growth Rate	Initial Fish Number	Final Fish Number	%Survival Rate
1	3,0	6,6	17	45	43	96
2	6,6	9,1	5,4	43	43	100

8th day was 8.6 g and the 14th day was 12 g, so the growth rate value was 5.6% per day for 7 days.

The number of fish at the end of the 1st week was 34, then at the end of the 2nd week there were only 28 fish. The number of tilapia deaths in the second week was much less than in the first week. The death of fish in the second week is still potentially caused by fish that are stressed and less adapted to the new environment. Based on the number of fish that are still alive, the fish survival rate is 82% (Table 5).

Based on the three fish samples taken, the average initial weight of the fish on the 1st day of the first week was 3 g, and on the 7th day was 6.6 g, the growth rate was 17% per day for 7 days. The number of fish on the 1st day of the 1st week was 45 fish, but on the 7th day of the 1st week, there were 43 fish left. The death of tilapia was caused by fish that were stressed and less adapted to the new environment and the presence of chlorine in the fish pond. Based on the number of living fish, the fish survival rate was 96%.

Based on the three fish samples taken, the average initial weight of the fish on the 8th day was 6.6 g, and on the 14th day was 9.1 g, the growth rate value was 5.4% per day for 7 days. The number of fish at the end of the 1st week was 43 fish and all fish still survived until the 14th day. So that the fish survival rate is 100%.

4 Conclusion and Suggestion

4.1 Conclusions

1. Based on the validation test before system integration, the MSP340 pH sensor has an average percent error of 2.58% and a percent accuracy of 97.42%. The SEN0237-A has DO sensor with an average percent error of 4.82% and a percent accuracy of 95.18%. Ultrasonic sensors have an average percent error of 3.14% and a percent accuracy of 96.86%.

2. Based on the ON-OFF control test on the system integration, the system can turn on and flow the solution with the actuator properly and according to the control logic design.
3. Based on the comparison of parameter values before and after the control system was installed, it was found that the pH value was still in the neutral pH setpoint range (6.5–8.5). While the DO value tends to be below the predetermined setpoint (1–5 mg/l).
4. Based on the comparison of plant growth rates, it was found that the plant growth rate decreased from 13.4% to 12.5% during the two weeks of the study due to external factors, but the plant length increased by 0.2 cm.
5. Based on the comparison of the growth rate of fish, it was found that the growth rate of fish increased in the first week using the control system to 17% and the Survival Rate was 100% in the second week.

4.2 Suggestions

1. In the manufacture of a control system for the degree of acidity and dissolved oxygen levels, it is necessary to add a control system for temperature parameters. Although temperature indirectly affects the control system, the temperature can increase and decrease carbon dioxide levels which directly affect the degree of acidity and dissolved oxygen levels.
2. At the time of designing the control system, it is necessary to select the right fish pond media. Do not use containers that are easy to leak or are made of conductors. The recommended container is glass or acrylic, to minimize indications of static electricity in pool water that can affect sensor readings.
3. Aquaponics can be placed in an open place and exposed to full sun, to maximize DO levels in the water and the photosynthesis process.
4. In the design of the plant, it is necessary to make a place that can contain sensors in the form of probes (pH and DO), to minimize reading errors.
5. In planting, the placement of kangkong seeds to be planted needs to be considered. It is better if the kangkong seeds are sown until they sprout before planting in aquaponics.

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