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Design and Implementation of Water Quality Control and Monitoring Devices in a Small-Scale Aquaculture System

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Abstract

To sustain an aquaculture system, one of the focus is on monitoring and controlling of water quality parameters. This study aimed at designing water quality control and monitoring system to be integrated and implemented in a developed small-scale aquaculture system. In this work, the necessary requirements needed for fish growth and development such as pH, salinity, ammonia and algae contents were being considered in developing different sensors for monitoring and control. The outcome of this work indicated the design and performance evaluation of the different sensors used to monitor and control the water parameters in the system. The implemented functionalities were able to monitor and maintain the pH, salinity, ammonia and algae contents in the aquaculture system. It can be recommended to also integrate in the system other water quality parameters such as oxidation-reduction potential, water hardness, nitrites and nitrates, among others.

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Introduction

Traditional farming such as in aquaculture basically has challenges when it comes to sustainability of operations. The manual and management operations must be there, as well as the maintenance of the water quality parameters (Hu *et al.*, 2019; Eze and Ajmal, 2020; Vo *et al.*, 2021; Rashid *et al.*, 2021). These problems maybe lessen using the smart approach wherein smart devices (Sharma and Kumar, 2021) and technologies (Ullah and Kim, 2018; Imai *et al.*, 2019; Kassem *et al.*, 2021; Tsai *et al*, 2022; Nagamora *et al.*, 2022) are integrated into the system to promote a sustainable, efficient and environment-friendly operation to attain good production. This is so because smart devices and technologies facilitate automated operations. They manage facilities and machinery therein and monitor water quality parameters (Kassem *et al.*, 2021). Smart farming, thus, is offering more advantages than the conventional one and is revolutionizing farming in general.

In an aquaculture system, for an instance, sensors were being developed to monitor and maintain water quality parameters (Aziz *et al.*, 2019; Balakrishnan *et al*, 2019; Tsai *et al.*, 2022; Nagamora *et al.*, 2022). Aziz *et al.* (2019) developed a monitoring system for continuously monitoring water quality. They came up with temperature sensor, light intensity sensor, pH sensor, GPS tracker and an inertial movement unit. Balakrishnan *et al.* (2019) designed an aquaculture system for controlling water parameters such as temperature, conductivity, turbidity and the nearness of oil layer over the water. Tsai *et al.* (2022) proposed an IoT-based smart aquaculture system for detecting the water quality of an aquafarm and providing automatic aeration such as temperature, pH value, dissolved oxygen and water hardness. Nagamora *et al.* (2022) integrated sensors in a small-scale aquaculture system for monitoring and control of light intensity, humidity, water temperature and dissolved oxygen. They recommended to include in the system sensors of other water quality parameters such as pH, oxidation-reduction potential and salinity, among others.

Water quality management is an essential part in aquaculture system. Water quality is a critical factor in the culture of any aquatic organisms for their growth and survival (Mustafa *et al.*, 2016). Traditional practice of water quality management requires human intervention. It includes sampling of water from the pond and testing it using test papers or devices in a laboratory (Tsai *et al.*, 2022). In order to minimize manual intervention, there is a likely a need to integrate smart technologies in the aquaculture system.

Hence, in this work, a continuation to the work of Nagamora *et al.* (2022) was conducted to integrate the control and monitoring of other water quality parameters in the developed small-scale aquacutlure system. Control and monitoring system was designed and implemented to maintain the parameters such as pH, salinity, ammonia and algae contents. Specifically, the performance of the different sensors used for controlling and monitoring the water parameters was evaluated. Furthermore, an automatic fish feeder was also considered to facilitate control of the production of algae in the system.

Methodology

System block design overview

The system design includes determining what sensors to be used together with its corresponding circuitry, the proper micro-controller to be used in programming, and also the software to be used to program the sensors using the micro-controller.

Control system design

The main purpose of the control system is to automate the control for the water quality of the system where it can adjust the water parameters like pH, salinity and ammonia content by using the liquid solution that doesn't need human intervention. Fig. 1 shows the control system block diagram.

The control system consist of three servos that interface with the Arduino uno micro-controller. The three servos are attached with liquid solution and the other one is attached with fish feeder to automate the system servos that uses 5V control signals from the Arduino which has been included to automatically switch ON and OFF when the sensor reading is above or below the water parameter requirements.

Monitoring system design

The main purpose of the monitoring system is to obtain the water quality parameter readings of the system displayed in the Liquid Crystal Display (LCD). By then, the data monitored is stored in the SD Card Module. The system can monitor the water parameters like pH, salinity, ammonia content and algae by using water parameter sensors. Fig. 2 shows the monitoring system block diagram.

The monitoring system consists of four sensors that also interface to arduino uno micro-controller. The sensors do have different water parameters to measure whose readings will be directly fed into the micro-controller so that they can be monitored and will be displayed to the liquid crystal display (LCD) and stored to the SD Card Module for review.

Overall system block diagram

Fig. 3 presents the overall system block diagram of the water quality control and monitoring system in small scale aquaculture system. The sensors used to feed the water parameters data to the micro-controller.

The micro-controller displays the data in Liquid Crystal Display and store the data in SD card module. In the system, if the micro-controller detects undesirable parameters, the control system will run the servo for liquid solution. The monitoring and control communication system is the essence of the whole aquaculture system. And that the micro-controller unit serves as the brain of the whole system.

Programming

Fig. 4 shows the general algorithm for the overall flow of programming the sensors. This is the main system algorithm serving as guide for programming the sensors. Without this, the sensors cannot function.

Algorithm for pH sensor

Fig. 5 shows the algorithm of the pH sensor. The first step is to start the pH sensor. The next step is to measure the water in terms of pH. If the pH value is greater than 7, the servo will remain OFF and if the pH value is less than 7, the servo will turn ON.

Algorithm for salinity sensor

Fig. 6 shows the algorithm of the salinity sensor. The first step is to start the salinity sensor. The next step is measure the water in terms of salinity. If the salinity value is greater than 0, the servo will remain OFF and if the salinity value is less than 0, the servo will turn ON.

Algorithm for ammonia sensor

Fig. 7 shows the algorithm of the ammonia sensor. The first step is to start the ammonia sensor. The next step is measure the water in terms of ammonia value. If the ammonia value is greater than 1, the servo will turn ON and if the ammonia value is less than 1, the servo will remain OFF.

Algorithm for algae sensor in the pond

Fig. 8 shows the algae sensor algorithm of the system. The algorithm seems only to measure the algae on the water and no involved controls. This is because the filtration system and food waste management system will help in controlling the algae production. These two systems would run 24 hrs. to help control the algae production.

Algorithm for algae sensor in filtration tank

Fig. 9 shows the algae sensor algorithm of the filtration tank system. The sensor measures algae or turbidity in the filtration tank. This will help to monitor the filtration tank if it needs to clean the filter so it provides response to the user to maintain the clarity of the water in the filtration tank.

Calibration

Calibration is a comparison between a known measurement (the standard) and the measurement using an instrument. Calibration is important to check the accuracy of the instrument. Fig. 10 below shows the flowchart of calibrating the sensors. There is a comparison between the sensors and reference sensor by measuring the water parameters to measure accuracy. The percentage error is set as 1% because that is a percentage acceptable for the accuracy of the sensor. In this study,the calibration involved the sensors of pH, ammonia, salinity and algae.

Performance evaluation

The system design must be tested and validated after it is developed. Testing is done by uploading the program on the actual micro-controller to see if the system runs. There is also assessment of the sensors (pH, salinity, ammonia and algae) to check if they read accurately and correctly. Troubleshooting is necessary for the consistency of the results being yielded. However, if the system works accordingly and properly as desired during testing, there is no need to do troubleshooting. Troubleshooting only happens when there is something needed to be fixed for the system to work and function accordingly as desired.

Results and discussion

Overall schematic system design

Fig. 11 shows the overall monitoring and control system desgin of the small scale aquaculture system. In monitoring system, four sensors are attached to theArduino micro-controller and for the control system, it attached 3 servos for liquid solution to control and maintain the water parameters of the pond. The data being fed into the micro-controller will immediately be displayed on the Liquid Crystal Display (LCD) and stored in the SD card module to collect data.

Table 1. Comparison of the Calibrated pH Sensor Reading and Reference Reading.

TRIALS	SENSOR READING	REFERENCE READING	PERCENTAGE ERROR
1	6.94	7.02	1.13960114
2	6.97	7.04	1.00430416
3	6.93	6.98	0.72150072
4	6.96	7.0	0.57471264
5	6.98	7.01	0.28612303

Monitoring system design

As in Fig. 12, the monitoring system is composed of four sensors, one data logger module, LCD and Arduino uno R3. This will help determine and monitor the water parameters. The list of sensors are the following: pH level sensor for the pH level of water, electrical conductivity sensor for salinity monitoring, turbidity sensor for algae monitoring, and MQ-137 ammonia sensor for ammonia monitoring.

Table 2. Comparison of the Calibrated Electric Conductivity Sensor Reading and Reference Reading.

TRIALS	SENSOR READING (ppt)	REFERENCE READING (ppt)	PERCENTAGE ERROR
1	33.42	33.76	1.017354877
2	34.79	35.11	0.919804541
3	35.02	35.24	0.628212451
4	34.85	35.02	0.487804878
5	35.04	35.12	0.228310502

The pH sensor is connected to analog input 0, EC sensor is to analog input 1, turbidity sensor is to analog input 2 and MQ-137 sensor is connected to analog input 3. Analog input 4 and 5 is for the LCD and digital input/output 13,12,11 and 10 is for the data logger. All of the components are then connected to the 5V and GND pin of the micro-controller.

Control system design

As shown in Fig. 13, the control system is consist of 3 servos connected in the Arduino digital pin 9, 8, and 7 and their power source and ground is connected to the battery. On the one hand, Fig. 14 shows the servo mechanism of the system. When the sensor detects intolerable level of parameters, it will feed direct to micro-controller then it commands the servo to rotate and release the liquid solution.

Filtration tank system design

Fig. 15 shows the filtration system design. The upper part is the filter tank and the lower is the sump tank. The filter tank is composed of screen (to keep the stone stable), zeolite stones and foam filter. The sump tank after the water filtered above the liquid solution will facilitate a release if the water parameters are above or below in their tolerable ranges and then will go through the pond.

Table 3. Comparison of the Calibrated MQ-137 Ammonia Sensor Reading and Reference Reading.

TRIALS	SENSOR READING (ppm)	REFERENCE READING (ppm)	PERCENTAGE ERROR
1	4.01	4.08	1.74563591
2	4.25	4.31	1.39211136
3	4.28	4.32	0.93457943
4	4.35	4.37	0.45977011
5	4.40	4.41	0.22727272

Table 4. Comparison of the Calibrated Turbidity Sensor Reading and Reference Reading.

WATER SAMPLES	SENSOR READING (NTU)	REFERENCE READING (NTU)	PERCENTAGE RROR	CATEGORY	TOLERABILITY
Sample 1	1090.85	1108.75	1.58878089	Clear	yes
Sample 2	1565.16	1584.68	1.24715684	Hazy	yes
Sample 3	2105.41	2123.74	0.86869790	Semi-Cloudy	no
Sample 4	2733.25	2749.42	0.59160340	Cloudy	no
Sample 5	2992.74	3004.15	0.38125597	Dark	no

Filtration tank system response

Fig. 16 shows the filtration tank system response where the turbidity sensor is connected to Arduino micro-controller and to the relay then to the buzzer. The system will be turned ON if the turbidity sensor detects undesired range of turbidity in the filtration system. This system will help facilitate awareness relative to the control of the turbidity level in the filtration tank. It is important to monitor and control the filtration system because the parameters would be dependent on the circulated water.

Liquid solutions for pH, salinity and ammonia

The pond area must be determined to calculate the required solution to be poured in the pond. The pond has a rectangular shape with a height of 40cm, width of 100cm and a length of 200cm. The average depth of water is 15cm.

Table 5. Automatic Fish Feeder per feeding time calibration result.

Trial	Iterations	Weight (g)	Tolerability
1	2	7	NO
2	4	15	NO
3	6	20	NO
4	8	27	NO
5	10	33	NO
6	12	38	NO
7	14	44	NO
8	16	49	NO
9	18	54	YES
10	20	61	NO

The amount of water in the pond could reach up to 300 liters. The dimensions would form the basis for calculating the required drops of pH, salinity and ammonia contents to the pond.

Fig. 17 shows the installment of the pH, salinity and ammonia liquid solutions in bottles. Each bottle is attached with the servo and filled with 50 ml of liquid solution. Fig. 18 shows liquid solution system installment in the sump tank. The servo is not synchronized. Only if the sensors would detect intolerable range that the servo will turn into 90° angle to release liquid buffer solution to adjust the water parameter ranges.

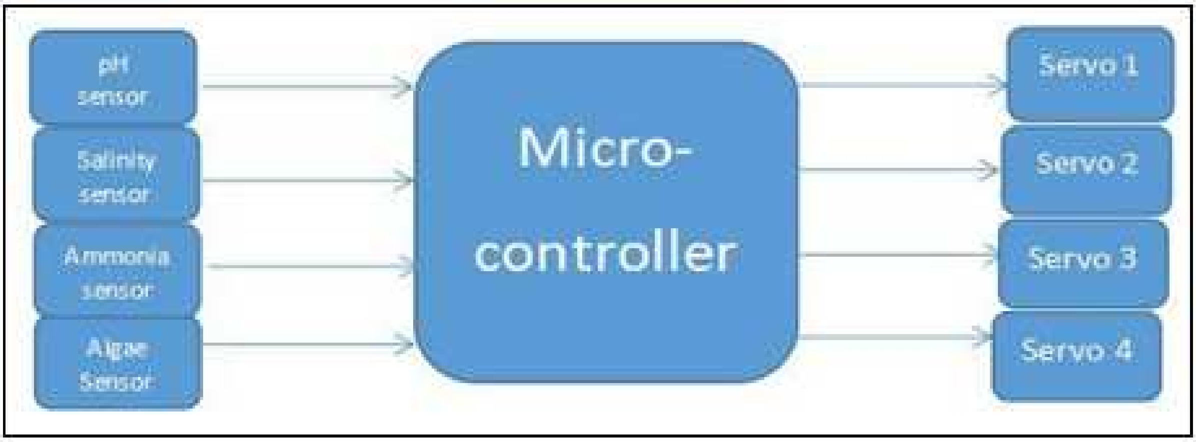

Fig. 1. Control System Block Diagram.

Fig. 2. Monitoring System block diagram.

Algae control solution

Fig. 19 shows the automatic fish feeder mechanism which facilitates algae control solution. The bottle is filled with food and tapped to the servo at 0°. When the servo wants to feed the fish it twists the bottle 180°. Food would fall out but also clog the holes so a very limited amount actually is dispensed. The servo immediately rights itself back and fort then to at 0° and waits for the next feeding. The food and bottle will both determine the quantity being dispersed. It has 6 hrs.-interval in their feeding time. The amount dispensed is consistent because the food will come out based on the living fish on the pond. If there is many fish, the program is adjusted to more iteration so servo will perform so that it can feed the exact amount pellets.

Calibration

pH Sensor Calibration

In calibrating pH sensor, the pH sensor probe and pH digital meter were tested and compated. This is to know the accuracy of the pH sensor probe with Arduino uno micro-controller. The pH value ranges from 0 to 14.

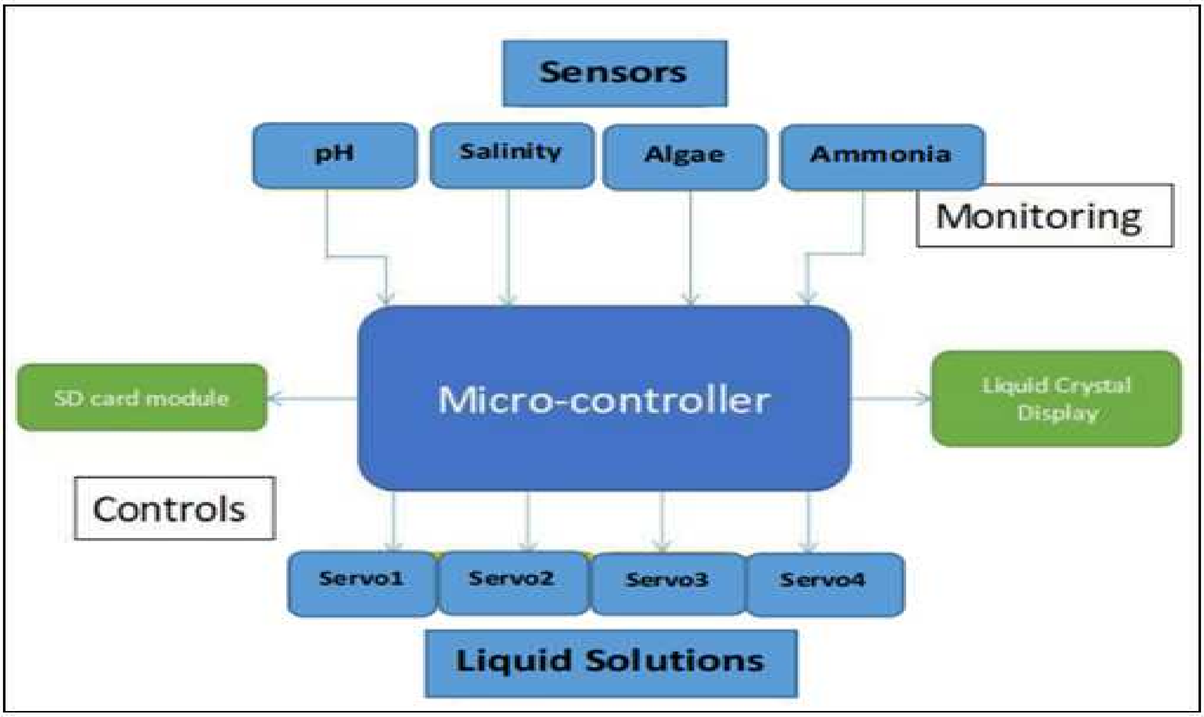

Fig. 3. Overall System Block Diagram.

The pH value of 7 and below has acidic value, 7 and up has alkalinity value and 7 is a fresh water value. The liquid sample used in the calibration test was a fresh water sample.

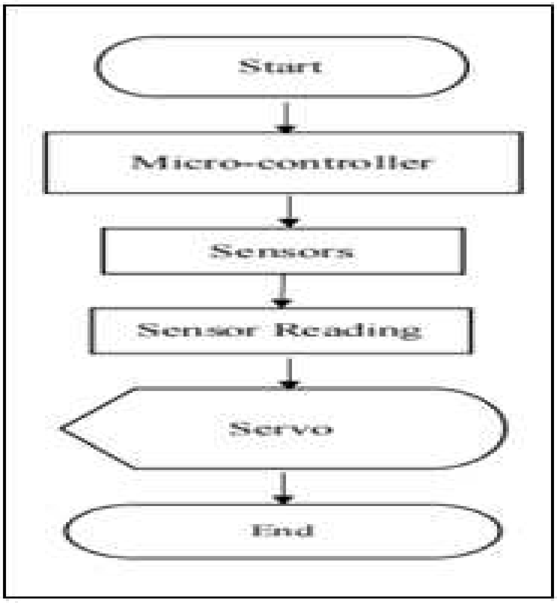

Fig. 4. General Algorithm.

Table 1 presents the data gathered on a fresh water liquid sample using the two sensors. The percentage error values shows are lower which means the sensor is quite accurate and reliable. Therefore, it is good and suitable to be implemented in the system.

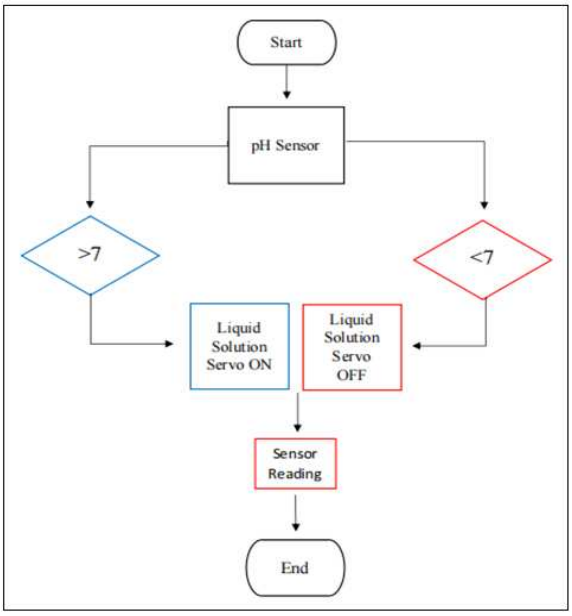

Fig. 5. Algorithm for pH sensor.

Electric conductivity sensor calibration

In calibrating the electric conductivity (EC) meter/sensor, the EC sensor probe and TDS digital meter were assessed and compared. This is to know the accuracy of the EC sensor probe with Arduino uno micro-controller. In salinity measurement, the value is being measured in ppt (parts per thousand). The liquid sample used in this calibration test was a salt water sample.

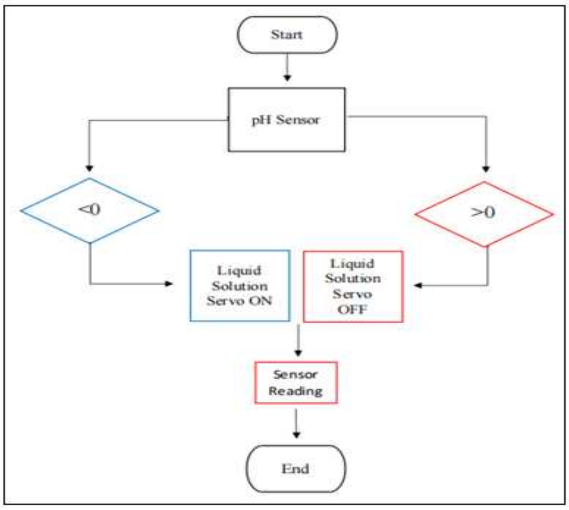

Fig. 6. Algorithm for Salinity Sensor.

Table 2 presents the data gathered on a salt water liquid sample using the two sensors. The percentage error values show that they are lesser than 5% which means the sensor is quite accurate and reliable. Therefore, the sensor is good to be implemented in the system.

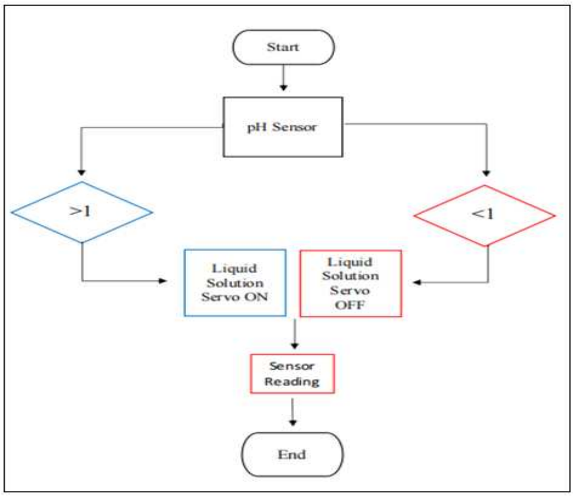

Fig. 7. Algorithm for Ammonia Sensor.

MQ-137 ammonia sensor calibration

In calibrating MQ-137 ammonia sensor, the MS-137 sensor probe and LaMotte smart 3 calorimeter were tested and compared. This is know the accuracy of the MQ-137 ammonia sensor probe with Arduino uno micro-controller.

In ammonia measurement, the value is measured in ppm (parts per million). The liquid sample used in this calibration test was an ammonium chloride sample.

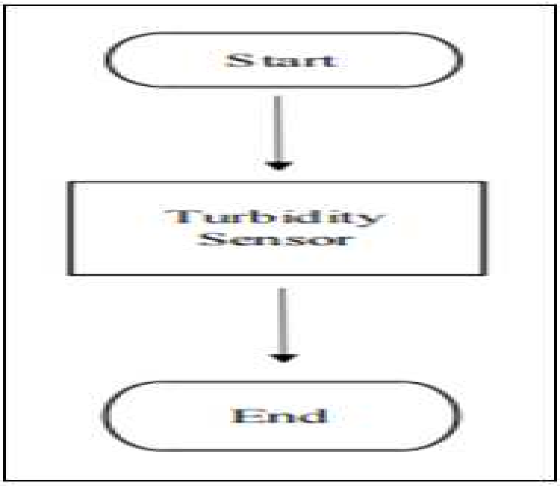

Fig. 8. Algorithm for algae sensor in the pond.

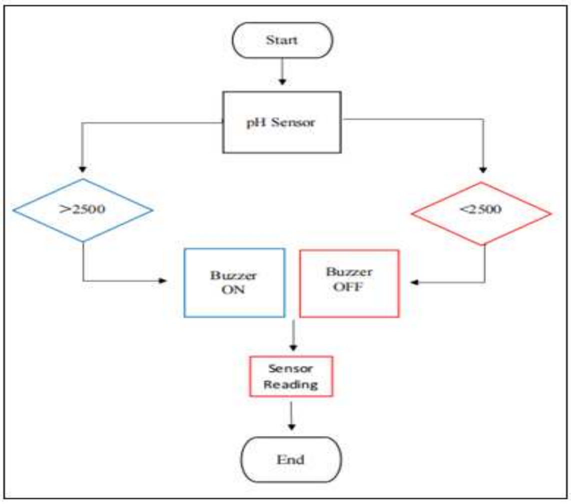

Fig. 9. Algorithm for algae sensor in filtration tank.

Table 3 shows the data gathered on ammonium chloride liquid sample using the two sensors. The percentage error values show that they are less than 5% which means that the sensor is also quite accurate and reliable. Therefore, the sensor is good and suitable also to be implemented in the system.

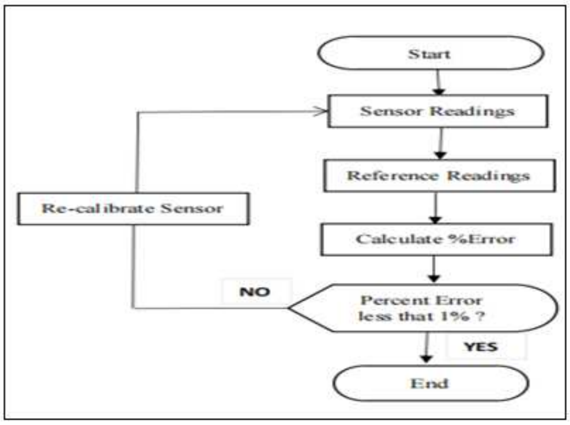

Fig. 10. Flowchart for Calibration.

Turbidity sensor calibration

In calibrating turbidity sensor, the turbidity sensor probe and also the LaMotte smart 3 calorimeter were assessed and compared. This is to know the accuracy of the turbidity sensor probe with Arduino uno micro-controller. In turbidity measurement, the value is measured in NTU (Nephelometric Turbidity Units). There were five samples of turbid water being used in such case.

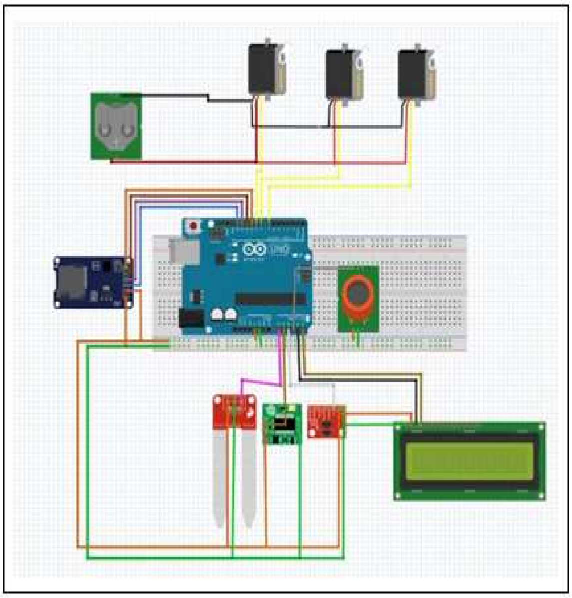

Fig. 11. Overall Schematic System Design.

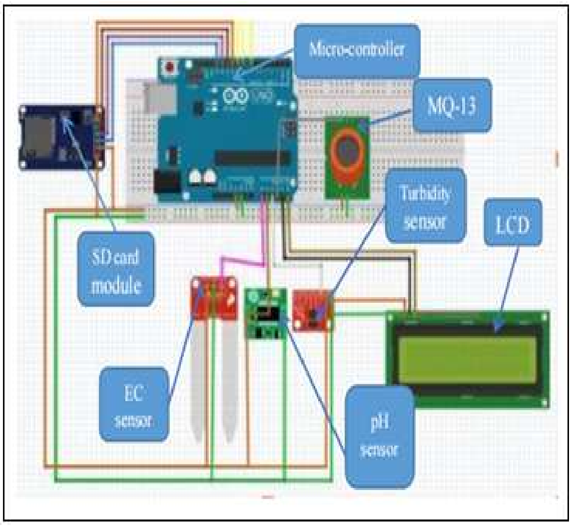

Fig. 12. Monitoring Device Schematic Design.

Table 4 presents the data gathered on five different liquid samples using the two sensors. It also includes the category and tolerability of a water to the fish. The percentage error values show very low results which means that the sensor is also quite accurate and reliable. And therefore, it is good also to be implemented in the system.

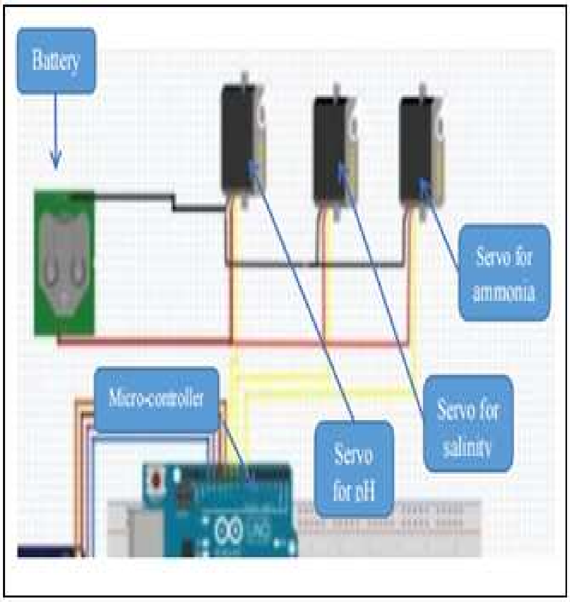

Fig. 13. Control Device Schematic Design.

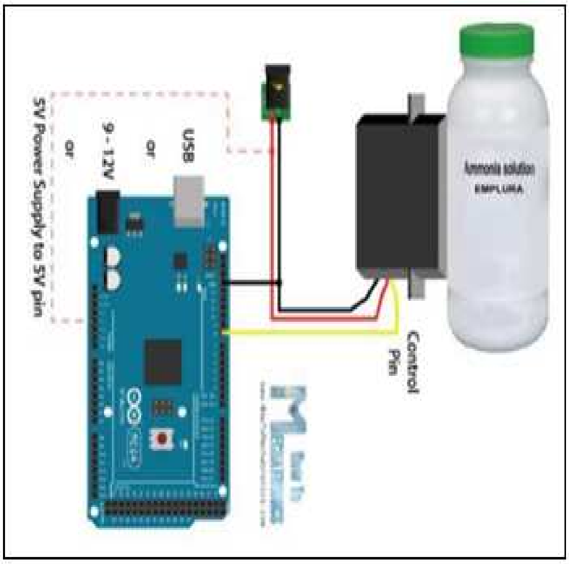

Fig. 14. Servo Mechanism.

The automatic fish feeder is one of the alternative solutions for algae production control to help reduce excess amount of food waste in the pond by feeding the fish exact amount of food or pellets. The fish feeder also needs to be calibrated to know the exact amount that will be fed to the fish.

The amount of food for fish fingerlings to be fed is usually 204 g in a day. If the feeding time of the fish is four times a day, there should be 51 g per feeding time.

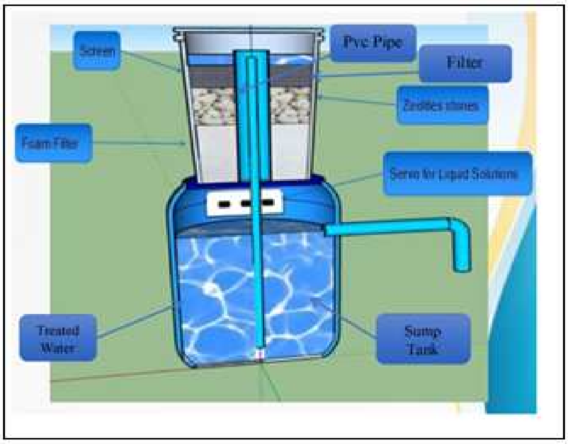

Fig. 15. Filtration System Design.

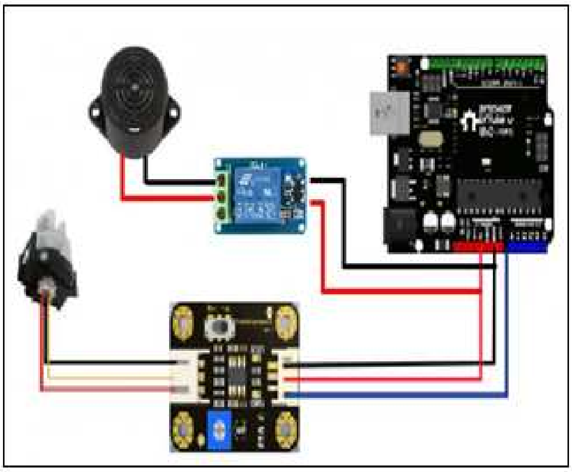

Fig. 16. Filtration Tank Turbidity Response.

Table 5 presents the data gathered on calibrating the automatic fish feeder. A total of 10 trials were performed to estimate the exact iteration to obtain the desired weight of food to be released in the pond.

Fig. 17. Liquid Solution placements of pH, salinity and ammonia.

The result obtained in the 9th trial was 54 g of fish food pellets which is the nearest to the desired amount of food being suggested. Therefore, in the automatic fish feeder, the device will perform 18 iterations to release 54 g of fish food four times a day to feed the fish.

Fig. 18. Liquid Solution system installed in the Sump Tank.

Performance evaluation

pH Monitoring and Control

Fig. 20 shows the water pH readings during the start of the monitoring. In general, the pH level readings of the system fluctuated. This is because of the filtration tank that kept the water of the system refreshed. It had a moment that it went down significantly at 12NN.

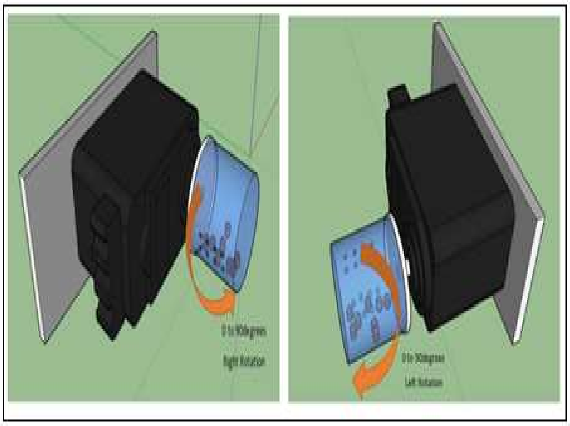

Fig. 19. Automatic Fish Feeder Mechanism.

In the 6th day of monitoring, the system monitored an undesirable range in which the pH level range dropped to 6.9. In such case, the control system will turn ON to treat the water and the servo will turn 90° angle and delay five seconds of time to release desired pH liquid solution then pour it into the water. Fig. 21 shows that the pH level of the pond went up after the desired pH liquid solution was applied into the warter.

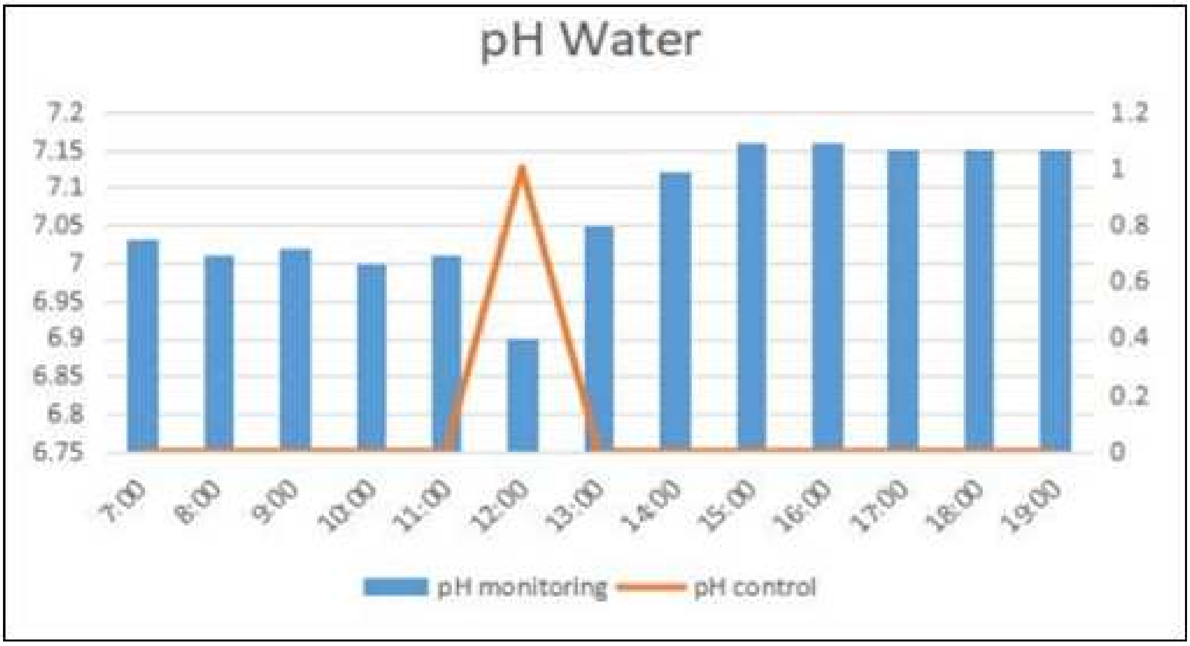

Fig. 20. Water pH readings of the System.

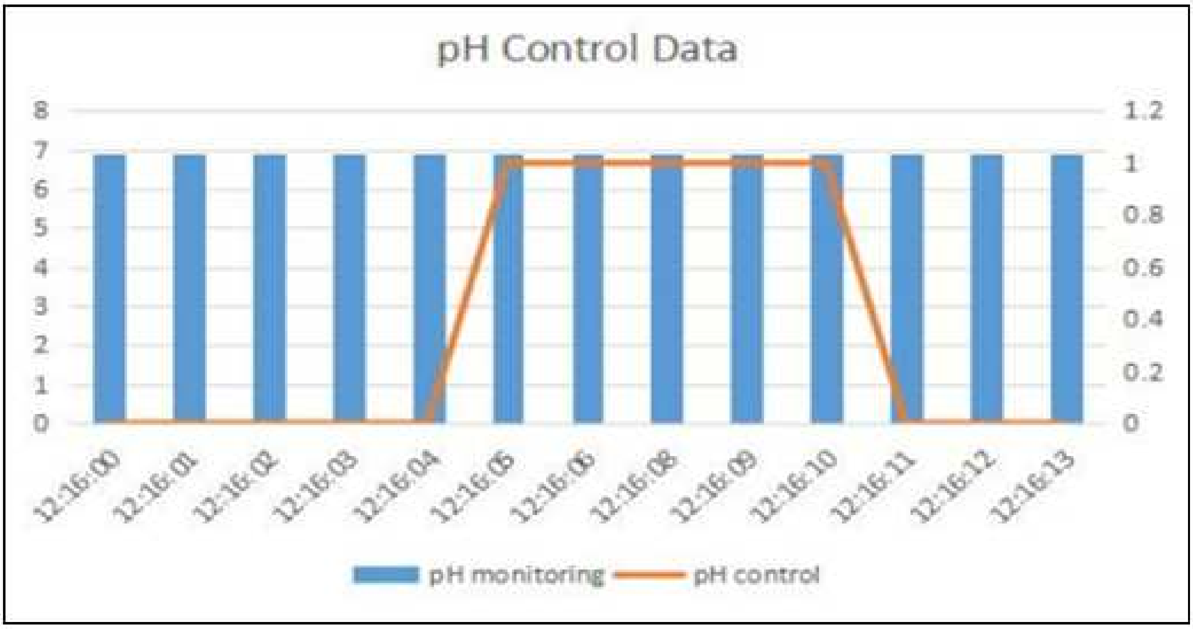

Fig. 21. Controlled water pH readings of the System.

Salinity Monitoring and Control

In the day of monitoring, Fig. 22 shows the data of salinity level of the system that went down for a time because of the filtration system that used to dissolve salts. During the 4th day of monitoring, the system monitored an undesirable range in which the salinity level range dropped to -0.01 ppt. As such, the control system will turn on to treat the water, the servo will turn 90° angle and delay 12 seconds of time to release desired liquid solution and pour it into the water. Fig. 23 shows that the salinity level of the pond went up after the desired salinity liquid solution was applied.

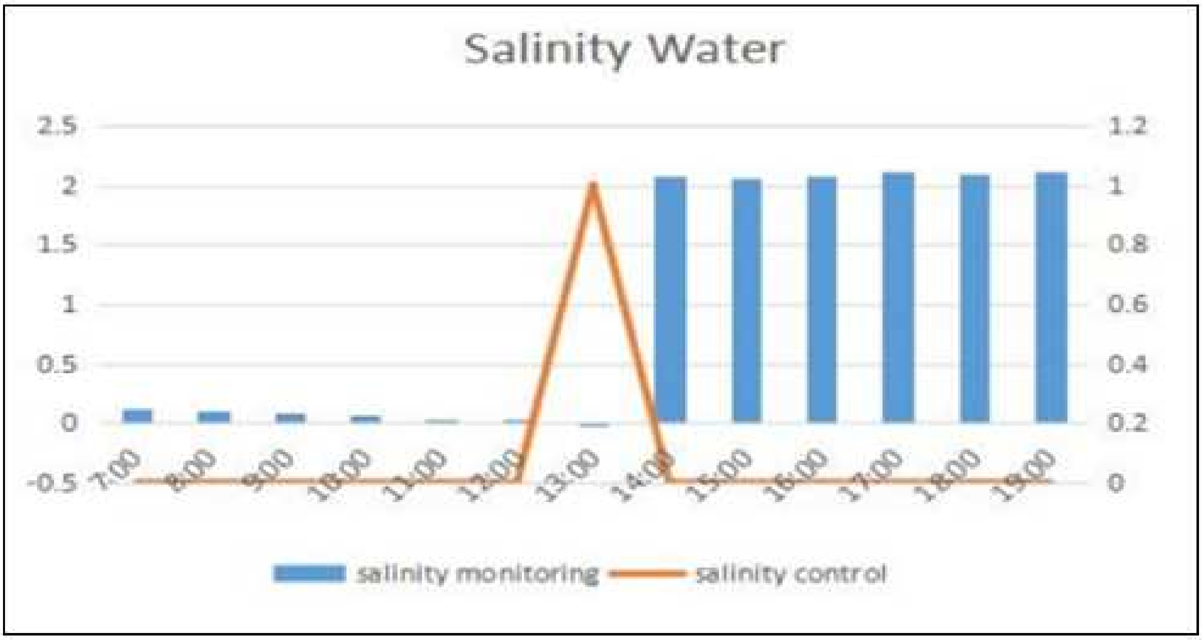

Fig. 22. Salinity level of the System.

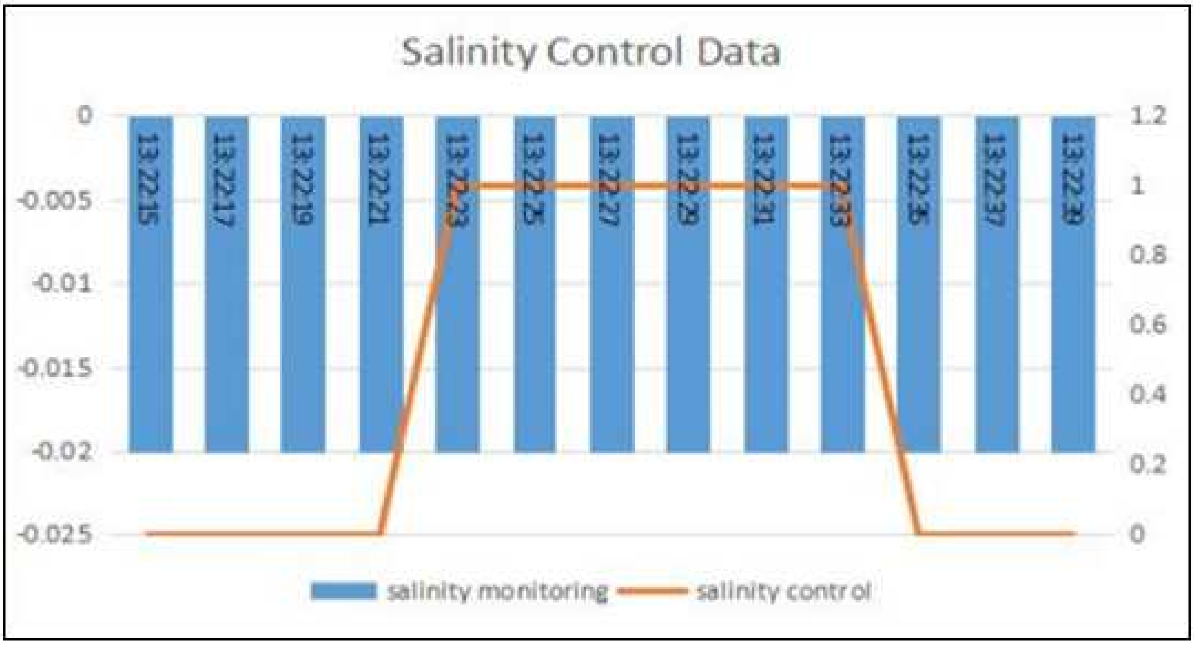

Fig. 23. Controlled Salinity Level of the System.

Ammonia monitoring and control

During the day of monitoring, ammonia content level of the system rose up at some point because of some wastes of the fishes that were not being filtered and stocked up in the corner as shown in Fig. 24.

However, during the 5th day of monitoring, the system experienced an undesirable range in which the ammonia content range rose up to 1.02ppm. In such a case, the control system will turn ON to treat the water, the servo will also turn 90° and delay 22 seconds of time to release the desired liquid solution and pour it into the water. Fig. 25 shows that the ammonia content of the pond dropped down after the desired ammonia liquid solution applied.

Turbidity Monitoring and response

During the 1st day of turbidity monitoring in the pond, the turbidity level went up as shown in Fig. 26. This is because of the wastes of the fish and some food wastes in the pond that caused cloudiness and haziness in the pond. Sooner or later the turbididty which implies presence of algae in the water will become an outbreak if not monitored. It is important to really put a filtration tank in the system in closed recirculating water pond like aquaculture to minimize unwanted specimens that flow in the pond.

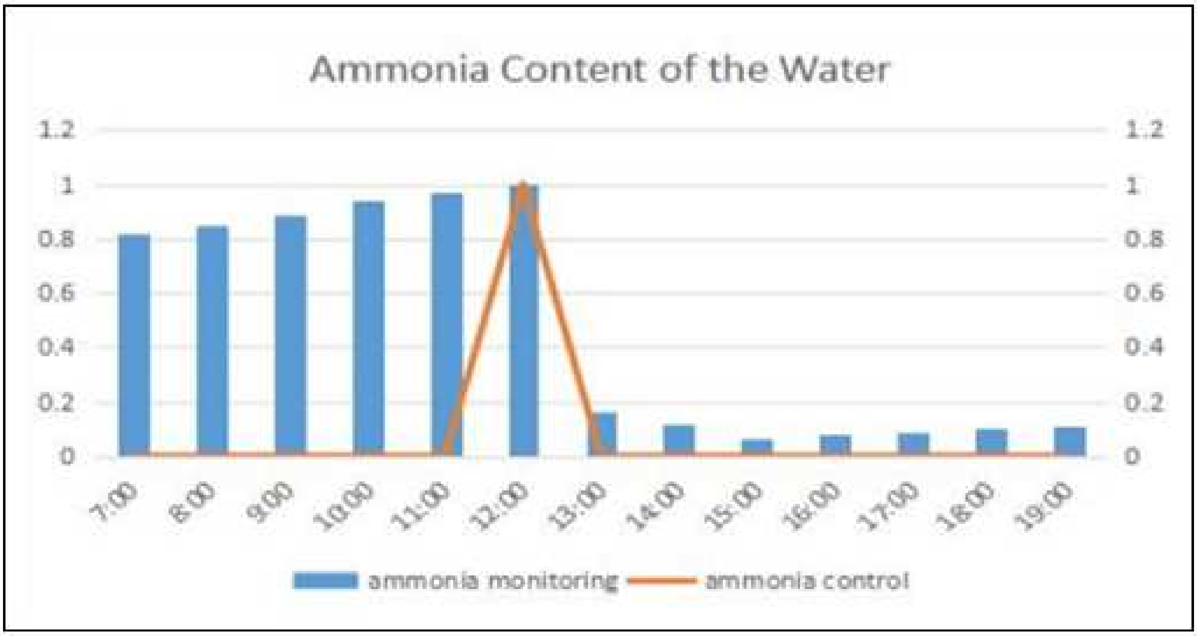

Fig. 24. Ammonia Content Level of the System.

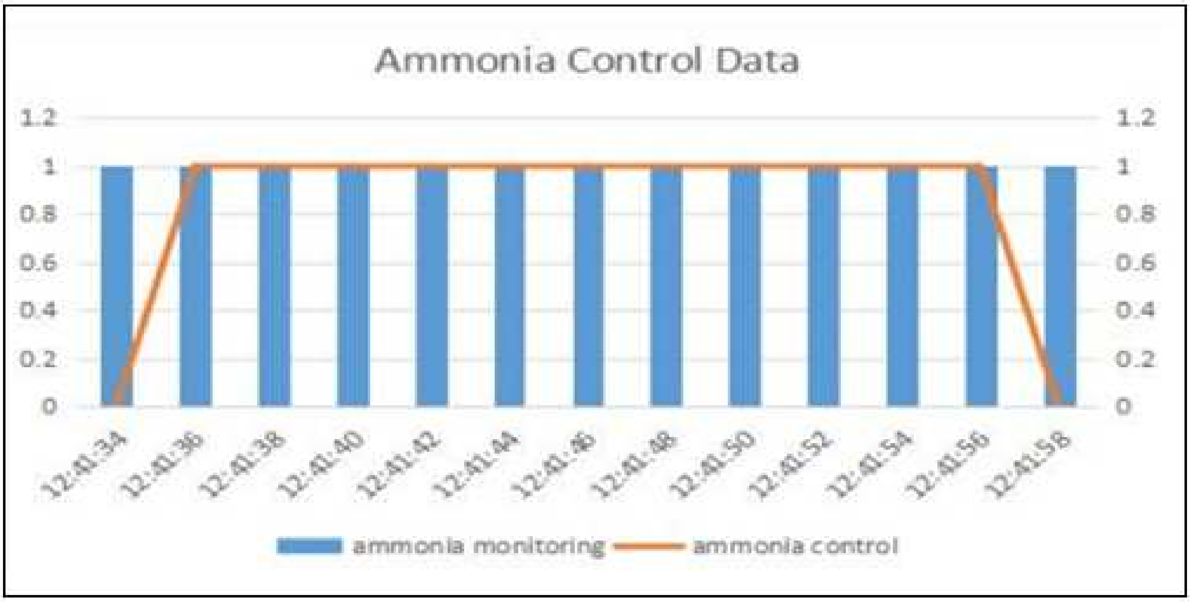

Fig. 25. Controlled Ammonia Level of the System.

On the 8th day of monitoring, there's this observation in the filtration tank on the turbidity level that reached up to 2500 NTU.

This is an undesirable range for the turbidity level as programmed so the buzzer response will turn ON as such. The tank in this case needs to be cleaned. On the 9th day, the turbidity level of the filtration tank is coming back to 1256.38 NTU as in Fig. 27.

This implies that the filtration tank had underwent cleaning already.

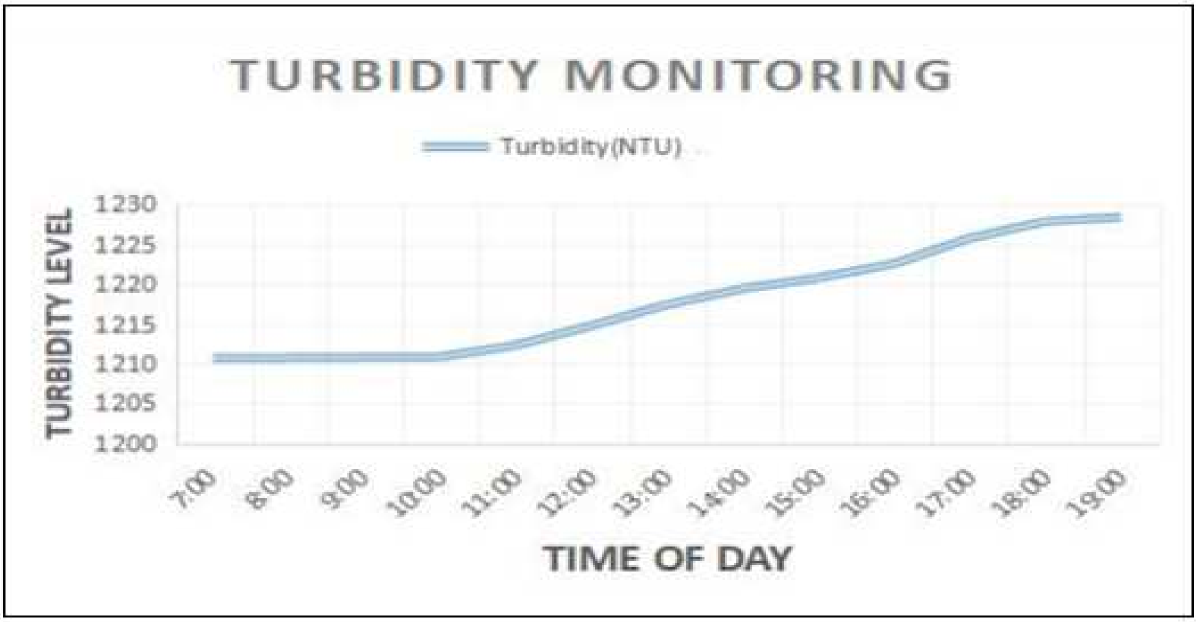

Fig. 26. Turbidity Level of the System.

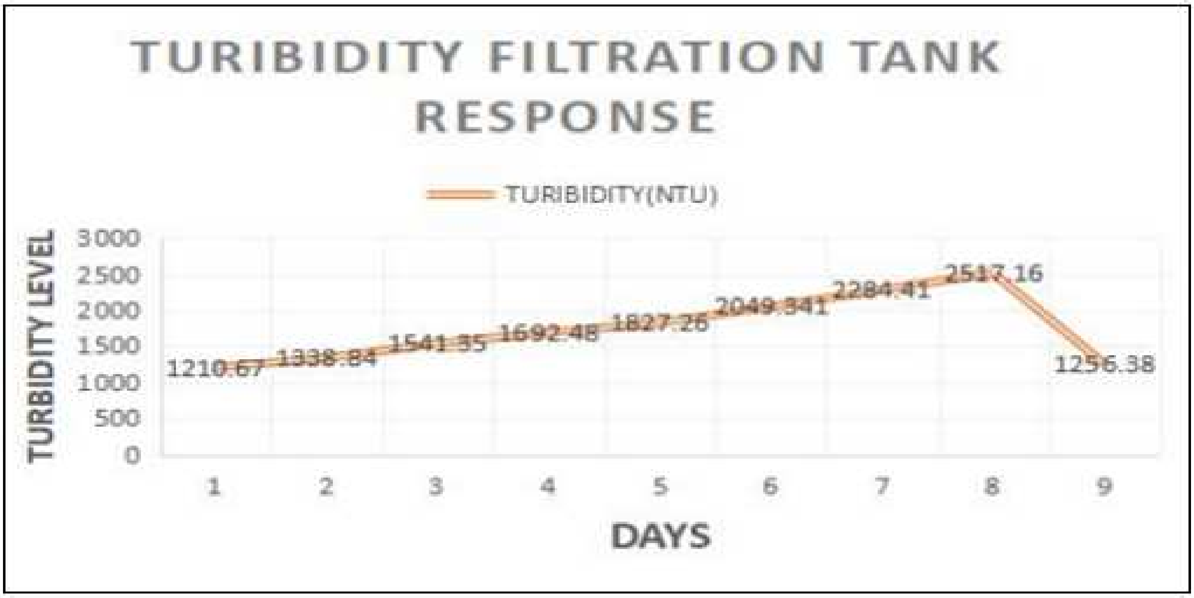

Fig. 27. Controlled Turbidity Level of the System.

Conclusion

In this study, the water quality control and monitoring system was developed to monitor the pH, salinity, ammonia and presence of algae in the small-scale aquaculture system. The functionality system was able to maintain proper pH, salinity, ammonia and presence of algae in the developed aquaculture system. On the one hand, the automatic fish feeder was also able to minimize the algae production by controlling the food that will be fed to the fish to avoid large amount of excess food wastes in the system. It can be recommended to also integrate in the system other water quality parameters such as oxidation-reduction potential, water hardness, nitrites and nitrates, among others.

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