Automated Water Quality Monitoring for Aquaponics Applied to Vertical Farming

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Abstract

Aquaponics is the process of growing plants and fish together in one system. The system mainly relies on the biotic relationship between fish and bacteria. Fish raised in aquaponics requires good water quality conditions as it is a major factor for the optimal growth of the fishes. However, in the current aquaponics implementation in the Philippines, the water quality parameters of the aquaponics are not monitored and controlled which affects the growth of fishes. This study focused on the development of a device that automatically monitors and controls the water quality parameters of aquaponics in application for vertical farming. The design of the device is based on the ideal water quality parameters suitable for growing tilapia such as ammonia, dissolved oxygen, pH level, temperature and turbidity. The device is capable of monitoring and measuring when one of the water quality parameters is not within its ideal value. Corresponding response will be made by the device to control and maintain the water quality parameters into its ideal value. The device was tested based on its accuracy and reliability. The tests shows that the pH level temperature sensors are 98.42% and 97.07% accurate, respectively. The test results also indicate that the water and pH level sensor of the device are 100% reliable as it functioned based on its expected output.

Keywords: **Aquaponics, Vertical Farming, Water Quality Monitoring and Control, Tilapia**

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I. Introduction

The agricultural land in the Philippines is continuously being developed into industrial areas, shopping malls, and subdivisions lowering the amount of crop yield production forcing the government to resort into new food production technologies that ensures food sustainability in urban growth.[1], [2]. The annual rapid growth of 1.21% in the Philippines is part of the rising urbanization that affects growing of natural resources thus results to food crisis [3], [4]. As stated by the United Nations, the need for localized food systems will be part of the future on how people will produce food and aquaponics is one of the current farming systems that has the potential to solve this type of problem [5]. The aquaponics has stack farming technique, which is used to increase production without acquiring additional land by planting in a stacked manner or in this study, vertical farming [6].

The aquaponics solves the problem in farming with less space available and vegetables planted provides nutrients directly to the fish [7]. It is not distinct from the aquaculture operation and the water quality parameters are considered as a major concern in the health risk assessment of aquaculture operation. Fish raised in aquaponics require good water quality conditions which means that parameters such as ammonia, dissolved oxygen, pH level, temperature and turbidity must be within its ideal range. However, according to Lake Management Office Bays Bayanan Baywalk, the research locale of the study, the growth of fish in aquaponics are affected because the water quality is not properly maintained.

The researchers utilized the advancement of agricultural operations and the information indicated by the Lake Management Office Bays Bayanan Baywalk to design and develop a device for aquaponics capable of automatically monitoring and controlling water quality parameters to maintain the growth rate of fish.

Table 1
Ideal range of water quality parameters for tilapia

Parameter	Ideal Range	Device Operation
Ammonia	0.02-0.05 mg/L	The device computes for the value of ammonia using the formula based on the study of Garcia et al., [8]. The ammonia level is considered good when both the pH and temperature is within the ideal range.
Dissolved Oxygen	≥5 mg/L	The aerator will turn on when the dissolved oxygen value is less than 5 mg/L.
pH Level	7-9	The pH up solution will be dispensed when the pH level is less than 7, while the pH down solution will be dispensed when the pH level is greater than 9.
Temperature	24 ºC-29 ºC	The heater will turn on when the temperature is less than 24ºC, while the aerator will turn on when the temperature is greater than 29ºC.
Turbidity	≥3.8V	The filter will turn on when the turbidity level is less than 3.8V.

Note. Ideal Range of Water Quality Parameters for Tilapia was derived from S. M. P. Garcia, C. L. B. Santos, R. Pula, M. A. G. Macasaet, K. M. E. Briones and S. M. L. Reyes, "Automated Water Quality Monitoring and Control for Milkfish Pond," World Congress on Engineering and Technology; Innovation and its Sustainability 2018, pp. 128-139, 2018.

II. Water Quality Monitoring and Control

The automated water quality monitoring and control device for aquaponics is focused only in culturing tilapia. The ideal range for each of the parameters must be determined to automatically monitor and control the water quality of an aquaponics.

Table 1 indicates the ideal range of good water quality parameters to be monitored, and the operations of the device to control and maintain the water quality in the ideal range. The device operation for each parameter works through the use of sensors.

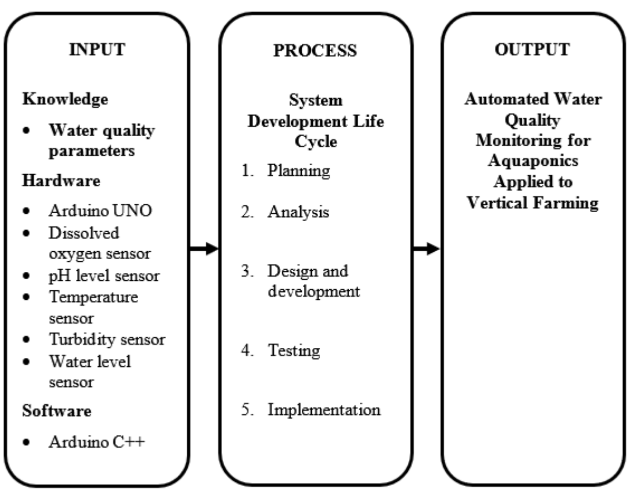


Fig. 1. Conceptual Paradigm of the Study

A. Knowledge

The existing IoT based water quality monitoring system for aquaponics is only capable of monitoring the pH and water level [9]. In addition, an existing study suggests an automatic controlling device when the monitored parameters are out of ideal range [10]. As an improvement of these studies, the developed device is capable of controlling the water quality parameters such as dissolved oxygen, pH level, temperature, and turbidity, it can also be monitored along with the water level and ammonia needed for the growth of the tilapia. The device is developed in the concept of stack farming, to increase the production and to maximize the nutrients that the tilapia is producing for the basil.

B. Hardware Design

This includes hardware components such as Arduino UNO for microcontroller and a number of sensors for the monitoring and controlling the water quality.

Figure 2 shows the physical design and different parts of the device. The device is divided into three major sections: (a) fish tank; (b) bedding; (c) drip irrigation and (d) solar panel.

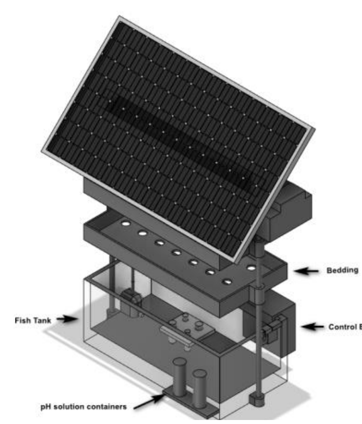


Fig. 2. 3D rendered prototype model of the integrated Aquaponics with Vertical Farm for the study

The fish tank is located at the bottom of the device where the tilapia is cultured. Attached to the fish tank is a control board that consists of the microcontroller board and LCD for the display of monitored parameters. At the back of the fish tank is the pH solution containers that holds the pH up and down solutions that control the pH level of the water.

The device has four sensors that measures each of the four water quality parameters: dissolved oxygen, pH level, temperature and turbidity. The float sensor measures the current water level while the heater warms up the water when the temperature is below its ideal range.

On top of the fish tank is a filter that controls the turbidity, and an aerator that controls the dissolved oxygen and cools down the water temperature. For the irrigation of the vertical farm, a water pump is installed that continuously pumps water to the vertical farm. On the top most part, the solar panel is installed where it charges the battery that serves as the main power source of the device.

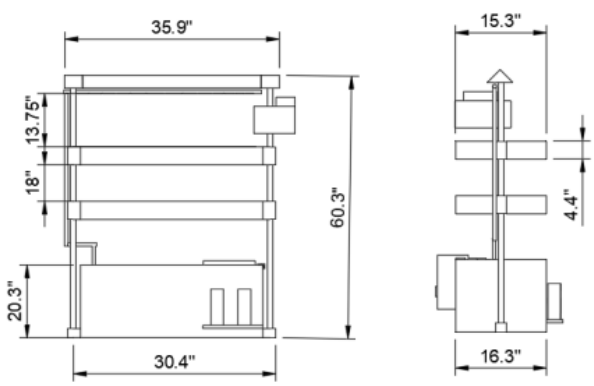
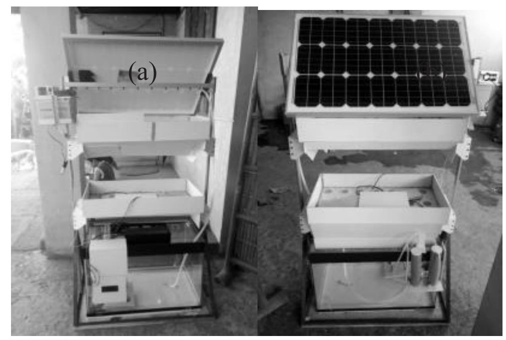


Fig. 3 – Front and side view measurements of the device

The dimension of the drawing in Fig.3 is 35.9” × 16.3” × 60.3”. The length is based on a standard-sized aquarium, while the height is designed to accommodate a two-layered bedding for vertical farming. The distance between the two beddings is 18 inches to accommodate the anticipated growth height of the basil, which is 12–18 inches.



(a) (b)

Fig. 4. (a) Back view and (b) front view of the assembled device

Fig. 4 displays the actual assembled device, (a) is the back view which shows the microcontroller board as well as the power supply while (b) is the front view which shows the solar panel and sensors of the device.

C. *Software Design*

The software program that operates the device is coded using Arduino C++, the programming language suitable for Arduino UNO.

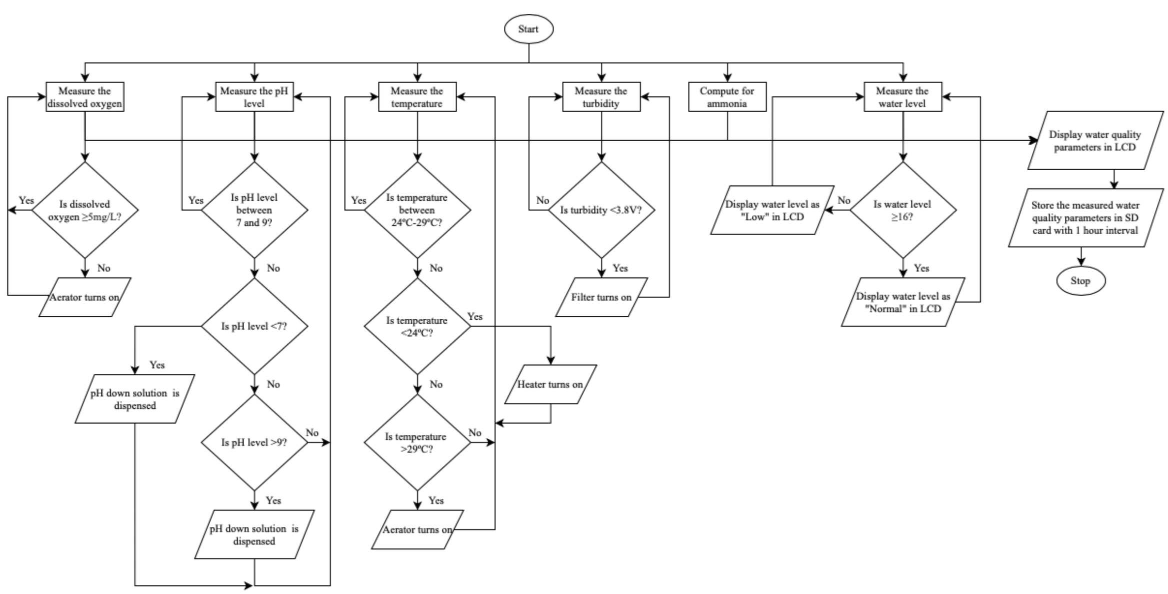


Fig. 5. Flowchart of the program

Table 2
pH ACCURACY TESTING OF THE DEVICE

Trial (Water Sample)	Time	pH Test Kit	Device pH Sensor	Percent Error	Remarks
1	13:17:59 PM	8.0	7.97	0.375%	Accurate
2	14:01:23 PM	7.5	7.46	0.53%	Accurate
3	14:27:50 PM	7.0	6.90	1.43%	Accurate
4	15:08:09 PM	8.5	8.37	1.53%	Accurate
5	15:31:27 PM	8.0	7.80	2.50%	Accurate
6	16:04:48 PM	9.0	8.91	1.00%	Accurate
7	16:15:52 PM	7.0	6.92	1.14%	Accurate
8	16:44:06 PM	8.0	7.80	2.50%	Accurate
9	17:21:39 PM	7.5	7.22	3.73%	Accurate
10	17:54:51 PM	6.5	6.43	1.08%	Accurate

The device is programmed to continuously measure and display all the parameters in the LCD. The control mechanism of the device comes with several conditions. If the dissolved oxygen is ≤5 mg/L, the device will automatically turn on its aerator. The aerator will continuously operate until the value of the dissolved oxygen is ≥5 mg/L. Another condition of the program is when the device detects that the pH level is <7, the pH up solution will be dispensed and when the device detects that the pH level is >9, the device will dispense its pH down solution. The same structure of code is implemented for the temperature control. When the temperature of the water is <24°C, the heater of the device automatically turns on, while if the temperature of water is >29 °C, the aerator will automatically turn on. Both the heater and the aerator will only stop operating when the temperature is within the range of 24°C-29°C. Next in the sequence, when the turbidity is <3.8V, the device will turn on its filter which will control the turbidity of the water and maintain it until it is within its ideal range. The ammonia is measured by using the formula based on the study of Garcia et al., [8] where the ammonia is based on the values of both the temperature and pH level. The monitored parameters are stored and logged into the micro-SD card with an interval of one hour to monitor the operation.

IV. EXPERIMENT AND RESULTS

A. Accuracy Testing

1. *PH Sensor Accuracy Testing*

Table 2 illustrates the accuracy testing for the pH sensor. A pH test kit is used to verify the pH level of 10 different water samples. On the other hand, the same water samples were also tested using the pH sensor of the device. The percentage error for each water sample between the pH test kit and pH sensor was calculated. The remarks for each water sample are "Accurate" if the percentage is within the ±5% tolerance value.

The results in Table 2 show that in 10 trials, the tested water samples are within ±5% of the evaluated tolerance percentage error. With this, the results indicate that the pH sensor of the device has an accuracy of 98.42%. The acquired accuracy rating proved that the device is capable of accurately measuring the pH level thus creating a balance environment which prevents the water to become too acidic or too basic which is harmful for the tilapia.

Table 3
Temperature accuracy testing of the device

Trial (Water Samples)	Time	Thermometer Temperature	Device Temperature Sensor	Percent Error	Remarks
1	13:02:27 PM	33 ºC	33.44 ºC	1.33%	Accurate
2	13:09:29 PM	33 ºC	32.25ºC	2.27%	Accurate
3	13:59:50 PM	34 ºC	35.44ºC	1.26%	Accurate
4	14:03:59 PM	34 ºC	35.56 ºC	4.59%	Accurate
5	14:26:47 PM	34 ºC	35.69 ºC	4.97%	Accurate
6	15:07:06 PM	35 ºC	36.19 ºC	3.40%	Accurate
7	15:30:42 PM	35 ºC	36.50 ºC	4.29%	Accurate
8	16:03:57 PM	36 ºC	36.25 ºC	0.69%	Accurate
9	16:44:30 PM	36 ºC	36.19 ºC	0.53%	Accurate
10	17:21:21 PM	34ºC	35.50 ºC	4.41%	Accurate

2. Temperature Sensor Accuracy Testing

Table 3 shows the accuracy testing for the temperature sensor used for the device. 10 water samples are tested with a temperature sensor and a thermometer. For each trial, the percentage error is calculated and evaluated as Accurate if the percent error is within ±5% tolerance value.

The results in Table 3 shows that the temperature sensor of the device is accurate for all water sample tested. With this, the results indicate that the temperature sensor of the device has an accuracy of 97.07%. This result proved that the device is capable of continuously maintaining the ideal water temperature needed by tilapia to obtain their optimal growth and survival.

B. Reliability Testing

1. PH Sensor Reliability Testing

Table 4 shows the reliability testing of the pH sensor of the device. The result of the pH test kit and pH sensor of the device are compared based on the standard scale of pH level. If both has the same scale of pH level, the trial is remarked as Reliable.

Table 4 shows that in 10 trials of water sample that came from the same water source, the pH scale of the pH sensor of the device is 100% reliable. The result shows that the device is stable and always correct in terms of its measuring the pH level of water. This proves that at any given time, the pH level of water is always at its ideal range.

Table 4
pH Reliability testing of the device

Trial (Water Sample)	Time	pH Test Kit	Device pH Sensor	Remarks
1	13:17:59 PM	7.5	7.97	Reliable
2	14:01:23 PM	7.5	7.86	Reliable
3	14:27:50 PM	7.5	7.81	Reliable
4	15:08:09 PM	7.5	7.79	Reliable
5	15:31:27 PM	7.5	7.78	Reliable
6	16:04:48 PM	7.5	7.72	Reliable
7	16:15:52 PM	7.5	7.67	Reliable
8	16:44:06 PM	7.5	7.62	Reliable
9	17:21:39 PM	7.5	7.22	Reliable
10	17:54:51 PM	7.5	7.23	Reliable

Table 5
Water Level sensor reliability testing of the device

Water Level (inches)	Time/Date	Expected Output (LCD Display)	Actual Output (LCD Display)	Remarks
20	11:10:03 AM/05-30-20	Normal	Normal	Reliable
18	13:32:00 PM/05-30-10	Normal	Normal	Reliable
16	14:56:04 PM/05-30-20	Normal	Normal	Reliable
14	17:15:26 PM/05-30-20	Low	Low	Reliable
12	18:14:12 PM/05-20-30	Low	Low	Reliable
10	21:08:15 PM/05-30-20	Low	Low	Reliable
8	08:57:26 AM/05-31-20	Low	Low	Reliable
6	12:33:45 PM/05-31-20	Low	Low	Reliable
4	14:42:46 PM/05-31-20	Low	Low	Reliable
2	15:24:55 PM/05-31-20	Low	Low	Reliable

2. Water Level Sensor Reliability Testing

Table 5 shows the reliability testing of the water level sensor of the device. The test is denoted as Reliable when the expected output is the same with the actual output of the device. The device displays the water level as "Normal" when the water level is ≥ 16 inches. Otherwise, the device will display the water level as "Low".

The results in Table 5 show that the tested 10 water levels were all marked as Successful. This indicates that the water level sensor of the device is 100% reliable. The results show that the parameters are always displayed correctly in the LCD at any given point of time and can always be monitored to determine if the water is maintained properly.

C. Summary of Test Results

The average percentage error for the accuracy of the pH level and temperature sensor are 1.58% and 2.93% respectively while the reliability of the device is measured as 100% reliable. The results acquired during these tests are better compared to studies related to water quality monitoring which acquired a percentage error of 5% in its tests results.

V. Conclusion and Recommendations

The device was able to measure values of ammonia, dissolved oxygen, pH, temperature and turbidity of the water. The results of the tests proved that the sensors of the device are all accurate and reliable proving its capability maintain and monitor the water quality of aquaponics in a vertical farm.

The accuracy and reliability can be further improved by using an ammonia sensor-compatible to a microcontroller board to directly monitor the ammonia in water. Provision of a user interface for better measurement display and for configuration of water quality parameters. The use of basil for the vertical farm and user of coconut coir as the growing medium is recommended due to the ideal pH range of these are compatible with tilapia [11], [12]

References

[1] S. Goddek, A. Joyce, B. Kotzen and M. Dos-Santos, "Aquaponics and Global Food Challenges," *Springer Link,* pp. 3-17, 2019.

[2] S. S. De Guzman, "Agriculture is Dying in the Philippines," 18 June 2018. [Online]. Available: https://www.philstar.com/opinion/2018/06/18/1825542/agriculture-dying-philippines.

[3] R. R. Romulo, "Looming Food Crisis," *PhilStar Global,* 30 August 2019.

[4] Philippine Statistics Authority, "Population Projection Statistics," Philippines, 2015.

[5] J. Snow, "Barangay Aquaponics Can Potentially Solve the Food Problem in the Philippines," *Good News Pilipinas,* 2017.
[6] N. S. Lee, S. Mustafa, M. B. Jalloh and J. N. W. Ling, "Production Efficiency of Stacked Aquaponics System," *Aquaponics Journal,* no. 61.
[7] S&T Media Service, "Expert Recommends Aquaponics for Urban Dwellers," 04 September 2014. [Online]. Available: http://www.dost.gov.ph/knowledge-resources/news/34-2014-news/594-expert-recommends-aquaponics-for-urban-dwellers.html.
[8] S. M. P. Garcia, C. L. B. Santos, R. Pula, M. A. G. Macasaet, K. M. E. Briones and S. M. L. Reyes, "Automated Water Quality Monitoring and Control for Milkfish Pond," *World Congress on Engineering and Technology; Innovation and its Sustainability 2018,* pp. 128-139, 2018.
[9] K. A. S. M. M. Muhamad Farhan Mohd Pu'ad, "IoT based water quality monitoring system for aquaponics," *Journal of Physics: Conference Series,* p. 7, 2019.
[10] P. C. Menon, "IoT enabled Aquaponics with wireless sensor smart monitoring," *IoT in Social, Mobile, Analytics and Cloud,* 2020.
[11] J. Simon, "How To Grow Basil: Tips On Planting and Harvesting," [Online]. Available: https://www.extension.purdue.edu/extmedia/HO/HO-189.html.
[12] King Star Global, "Vertical Farming with Coco Peat," [Online]. Available: http://www.kingstar-global.com/hydroponics.php.