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An Assessment of the Control and Monitoring Functionalities of a Developed Small-Scale Aquaculture System

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Abstract

In smart aquaculture, devices and technologies are integrated to facilitate automated operations, manage facilities and machinery and maintain water quality parameters. This study aimed at assessing control and monitoring functionalities in an automated small-scale aquaculture system. In this work, the requirements to sustain aquaculture systems such as light intensity, humidity, water temperature and dissolved oxygen have been considered in the selection of appropriate sensors for monitoring and control. The controls of the system were able to maintain proper light intensity, water temperature, and humidity. Water aeration also provided enough dissolved oxygen into the system. The outcome of this work indicated the performance and testing of the different sensors for monitoring and controlling parameters to sustain the automated aquaculture system. It can be recommended to include in the study other important parameters such as pH, oxidation-reduction potential, and salinity, among others. It can be recommended to provide more water heaters for fast water heating in the system. And if the system is being applied to a naturally hot area, a cooling study or assessment may also be made.

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Introduction

Urban farming is growing food within urban areas to facilitate and promote food sustainability (Andini *et al.*, 2021; Sroka *et al.*, 2021; Atmaja *et al.*, 2020). It includes techniques such as vertical farming, indoor farming, hydroponics, aeroponics, aquaculture, and aquaponics (Ng and Mahkeswaran, 2021). Nowadays, it is considered a trend in agriculture (Gulyas and Edmonson, 2021; Langemeyer *et al.*, 2021; Komalawati *et al.*, 2022; Sia *et al.*, 2022; Jamali *et al.*, 2022). Komalawati *et al.* (2022) considered it a resilient strategy in this new normal for enhancing food availability and reducing stress among households.

Urban farming techniques may not at all revolutionize farming unless they are incorporated with technological innovations such as the internet of things (IoT), automation, artificial intelligence, and robotics among others; to attain full potential and gain many advantages (Ng and Mahkeswaran, 2021). Technological innovations in urban farming techniques would lead to sustainability in operations. These would lead to more benefits as compared to traditional farming. Traditional farming as in aquaculture may pose problems with the manual and management operations and the sustainability and/or maintenance of water quality parameters as well (Hu *et al.*, 2019; Eze and Ajmal, 2020; Vo *et al.*, 2021; Rashid *et al.*, 2021).

Such existing problems in traditional aquaculture may be solved in a smart aquaculture approach, that is, if several smart devices (Sharma and Kumar, 2021) and other technologies are integrated such as IoT, and artificial intelligence (Imai *et al.*, 2019; Kassem *et al.*, 2021), big data, 5G, cloud computing, and robotics. These technologies would allow a system to be operated automatically, manage facilities and machinery therein and real-time monitor water quality parameters such as temperature, dissolved oxygen, humidity, light and pH. This is, thus, promoting a sustainable, efficient and environment-friendly operation to attain good production (Kassem *et al.*, 2021).

In this work, a developed automated small-scale aquaculture system has been studied in terms of its control and monitoring functionalities. The goal was to monitor and maintain the system's parameters such as humidity, light intensity, water temperature and water aeration. Further, the system's long-term and actual performance were also assessed. Locally, there are already available aquaculture systems carried out in manual practices and require power coming from the electric utility thereby adding to the electric consumption. This automated aquaculture system operates also at night time and is solar-powered in response to traditional aquaculture which depends on sunlight and cannot give a constant and sufficient amount of health benefits required by the fish. The sudden change in weather cannot be predicted and might cause abrupt changes also in temperature as well as humidity. Sudden changes in temperature and humidity of the pond and its area will give stress to the fish and must be taken into consideration also. Smart lighting is also a major part of the said work for it will help the system operate at its fullest.

Methodology

Design overview

Fig. 1 below shows the block diagram of the system. The relay was connected to the load which would be triggered by the microcontroller unit. With this, a signal is sent to activate the relay to control the loads and the sensors will send data to the microcontroller. Then, the data from sensors will be displayed through Liquid Crystal Display (LCD).

Figs. 2 and 3 show the control and monitoring system overview and schematic diagram. The battery would supply the sensors and load with the use of a voltage regulator to control the voltage to suit the requirement of each component. The main brain of the system is the Arduino microcontroller. It is where the parameters are being controlled. The sensors would send data to the microcontroller, which then the microcontroller displays in the LCD. When the data are read by the microcontroller, automation follows. If the sensor detects that the system has low humidity and high temperature, it turns on the humidifier. If the sensor detects that humidity outside the controlled environment is better than that of the inside, it turns on the exhaust fans. If the sensors would detect that the light intensity in the system is not enough, it turns on the light. If the sensor detects that the water temperature is below the required parameter, it turns on the water heater. Then, if the required parameters are met, the load automatically turns off, then turns on automatically if there is a parameter that is not suitable for the fish.

Programming

This is where the brain of the control system is. Without this part, the system cannot function as desired. In this section, the general algorithm and the program algorithm of each sensor are presented. For humidity monitoring, the DHT22 sensor was employed in the system. For the water temperature, DS18B20 sensor was used. And for light intensity in the system, KY-018 was utilized.

General algorithm: The general algorithm is shown in Fig. 4 below.

Program algorithm for DHT22 sensor (Humidifier):
Step 1: Start
Step 2: Read Sensor Values
Step 3: If Humidity is ≤ 70%, turn on humidifier.
Else, turn off humidifer
If Humidity is ≥ 95%, turn off humidifier.
Else, turn on humidifer
If Humidity is ≥ 70% ≤ 95%, turn off humidifier
Else, turn on humidifer
If Humidity is = 70%, turn off humidifier.
Else, turn on humidifier
Step 4: Display Humidity Values
Step 5: End

Program algorithm for DHT22 sensor (Fans):
Humidity1 = Humidity Outside
Humidty2 = Humidity Inside
Step 1: Start
Step 2: Read Sensor Values
Step 3: If Humidity1 is ≤ Humidity2, turn on fans.
Else, turn off fans
If Humidity1 is ≥ 70% ≥ Humidity2 , turn on fans.
Else, turn off fans
If Humidity1 is ≤ 70% ≥ Humidity2 , turn on fans.
Else, turn off fans
If Humidity1 is ≤ 70% ≤ Humidity2 , turn off fans.
Else, turn on fans
If Humidty1 is = Humidity2, Turn off fans.
Else, Turn on fans
Step 4: Display Humidity Values
Step 5: End

Program algorithm for KY-018 sensor (LED Lights):
Step 1: Start
Step 2: Read Sensor Values
Step 3: If Lux ≥ 60% (600 lux), turn off lights.
Else, turn on lights
If Lux ≤ 60% (600 lux), turn on lights.
Else, turn off lights
If Lux = 60% (600 lux), turn off lights.
Else, turn on lights
Step 4: Display Light Lux values
Step 5: End

Program algorithm for DS18B20 water temperature sensor (Heater):
Step 1: Start
Step 2: Read Sensor Values
Step 3: If Temperature ≥ 27°, Turn Off Heater
Else, Turn On heater
If Temperature ≤ 27°, Turn On Heater
Else, Turn Off Heater
If Temperature = 30°, Turn OFF Heater
Else, Turn On Heater
Step 4: Display Temperature and Humidity Values
Step 5: End

Program algorithm for water Aerator:
Step 1: Start
Step 2: Read Time Value
Step 3: If Delay ≥ 0 < 43200, Turn on Aerator
Else, Turn off Voltage Aerator
If Delay ≤ 43200 Turn off Voltage Aerator
Else, Turn on Aerator
If Delay = 43200, Turn on Aerator

Step 4: End

Program testing, verification and system implementation

In this stage, the system being developed was tested and validated thru experimentation. Testing was done by uploading the program on the actual microcontroller to see if the system runs or if ever the system works. In order to validate if the system is working, sensors, together with the loads are being connected to see if it functions according to the desired output. If ever the circumstances of the system will not meet the set conditions, the system would undergo redevelopment until the conditions are met.

Whenever there are no more errors encountered during testing and verification, implementation would follow afterward. System implementation must be according to the tested and validated program. However, if the system fails to work, troubleshooting would follow until the desired result is obtained.

System troubleshooting

Troubleshooting was carried out by checking the connection of the system to each component that is connected, and also checking the pins on every sensor and load whether they are connected properly without any short circuits. Recalibrating stage would also be performed at this point. Even if the devices or sensors were already calibrated during the manufacturing stage, there is a need to recalibrate them in order to see if the said devices are still in good condition.

Troubleshooting the system only happens when there is something to be fixed so that it will work as desired. Some errors need to be determined and fixed until the system achieved the desired output.

Research setting

The study was conducted at Barangay San Miguel, Manolo Fortich, Bukidnon, Philippines.

Results and discussion

KY-018 photoresistor module testing

Fig. 5 below shows light intensity varying through time without the system. In the area where the system is being installed, light intensity wasn't present from the time 3 AM to 6 AM. So, as shown in the graph, the light is low. From the time, 7 AM to 1 PM, the light lux was enough and was changing from low light to bright light. Light intensity tends to decrease in the time 2 PM to 1 AM.

Table 1. Comparison of light intensity through height.

Light Height from the Surface of water (m)	Lux
0.70	600-620
0.60	800-835
0.50	950-1010

On the other hand, Fig. 6 below shows that the light intensity was varying over time with the lighting system. Specifically, shows the graph of lux within the system with automatic control. Since the light is only required for 12 hours a day, light can only turn on between time of 6 AM to 6 PM in the system. From 6 AM, lux was still low because the sun was yet to shine and the lux it gave wasn't enough.

Table 2. Percentage error of KY-018 sensor.

Trial Low Value	Sensor reading	Reference reading	Percent reading (%)
1	1005	1000	5.0
2	1000	1000	0
3	999	998	1.0
4	1000	998	2.0
5	999	999	0
6	1000	1000	0
7	1000	1000	0
8	1000	1000	0

The sensor detected that the light wasn't enough by the time so, the light turned on at a constant intensity at 6 AM.

From 7 AM to 12NN, the sunlight, this time, was enough to sustain the fish. The automatic light then switched off. And as shown in the graph, the artificial light by the system was replaced by natural sunlight. Since the light from 3 PM to 6 PM wasn't enough, the automatic light turned on and as shown, lux was constant because the light intensity has been sustained by the artificial light. After 6 PM, the light was no longer needed, so the automatic light turned off.

Table 3. Percentage error of DHT22 sensor.

Trial	Sensor reading		Reference reading		Percent error (%)	
	Temperature (°C)	Humidity (%)	Temperature (°C)	Humidity (%)	Temperature	Humidity
1	26.9	76	26.7	75.9	0.2	0.1
2	26.9	78	26.8	75.7	0.1	2.3
3	26.9	77	26.8	75.7	0.1	1.3
4	26.8	77	26.7	75.9	0.1	1.1
5	26.7	76	26.7	75.9	0	0.1
6	26.7	75	26.7	75.9	0	0
7	26.7	75	26.7	75.9	0	0

Table 4. Percentage error of DS18B20 sensor.

Trial low value	Sensor reading	Reference reading	Percent error (%)
1	26.8	27.9	1.1
2	26.9	27.9	1.0
3	27.6	27.8	0.2
4	27.9	27.8	0.1
5	27.8	27.9	0.1
6	27.8	27.8	0
7	27.8	27.8	0
8	27.8	27.8	0

Fig. 7 below shows the light strip's layout. The light strips used in the area were a 12 V-light with a length of 5 m, enough to cover a 150 cm x 100 cm area if divided equally. To be able to divide the lumense the light strips emit, the pond's area was divided three (3) times vertically with exact spacing, enough for the light strips' length to cover the area. The exact amount of length used in the pond was 450 cm. Each beam that carries the strip light has fifty-eight (58) led lights, respectively, a total of 174 LED lights. The placement of the light in the system has a major factor in the lumense it would give.

Table 5. Percentage error of sensor readings.

Sensor	Sensor reading during the first day	Sensor reading after three weeks	Percent error in the system (%)
DHT22 (Humidity)	90.0%	89.7%	0.334482
DHT22 (Temperature)	27 (°C)	26.8 (°C)	0.2462687
DS18B20 (Water Temperature)	27 (°C)	26.9 (°C)	0.3717472
KY-018 (Lux)	1000 lux	999.5 lux	0.5

The farther the light is to the surface of the water, the lesser lumense it would give. In order to achieve the 1000 lux that is needed in the system, the light was adjusted in its height in order to attain the 1000 lux required for the fish. After adjusting the height at 48 cm from the surface water to the light, the exact height would be 48 cm. So the light was placed 48 cm above the surface of the water (Fig. 7).

Table 6. Dissolved oxygen in every part of the pond.

Part	Dissolved Oxygen (mg/l)
Upper Left of the Pond	7.11
Center Top of the Pond	7.19
Upper Right of the Pond	7.18
Center Left of the Pond	7.02
Center of the Pond	7.20
Center Right of the Pond	7.16
Lower Left of the Pond	7.03
Center Lower of the Pond	7.06
Lower Right of the Pond	7.10

Table 7. Growth development of red tilapia in the system.

Period	Weight (g)	Length (cm)
Day 1	7.60	2.75
Week 1	10.96	3.10
Week 2	14.32	3.55
Week 3	20.80	4.00

Table 1 below shows the lux it would give by height. If the luminaire was placed above surface water for 0.70 m, the lux in the surface water was in the range, of 600-620 lux. Then if the luminaire was placed 0.60 m above the surface water, the lux was in the range of 800-835 lux. If the luminaire was placed above surface water for 0.50 meter, the lux was in the range of 950-1010 lux.

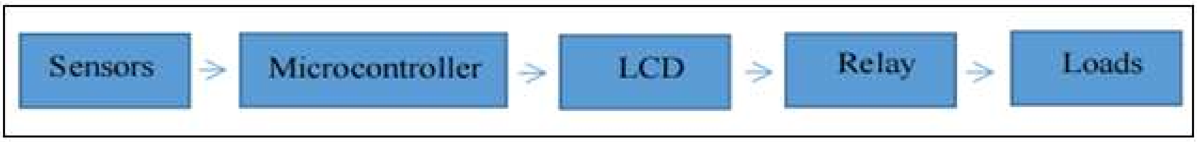

Fig. 1. Block diagram of the system.

DHT22 sensor testing (Humidity)

Naturally, the humidity is high in Manolo Fortich, Bukidnon. As shown in the graph below (Fig. 8), humidity from 3 AM-7 AM was very high, the area was colder and the air was humid. From 7 AM-12NN, the humidity, as shown in the graph, decreased. The lowest humidity outside the system reached 70% which is not a critical parameter. From the period, 12NN-7 PM, humidity increased in the area. Lastly, from 8 PM-2 AM, the humidity came back to a very high level.

On the other hand, Fig. 9 above presents the humidity inside varying through time without the system running. The graph shows that the humidity outside is better than the humidity inside. Without automatic control, the humidity inside was less than the required parameters. The lowest humidity in the inside system reached almost 50% which is a critical parameter.

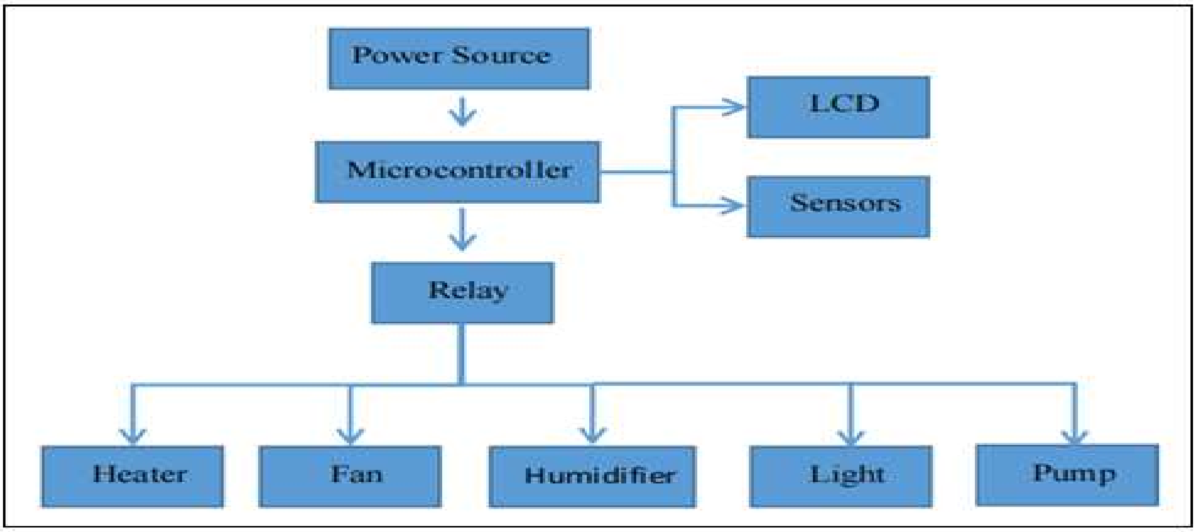

Fig. 2. Controls and monitoring system schematic diagram.

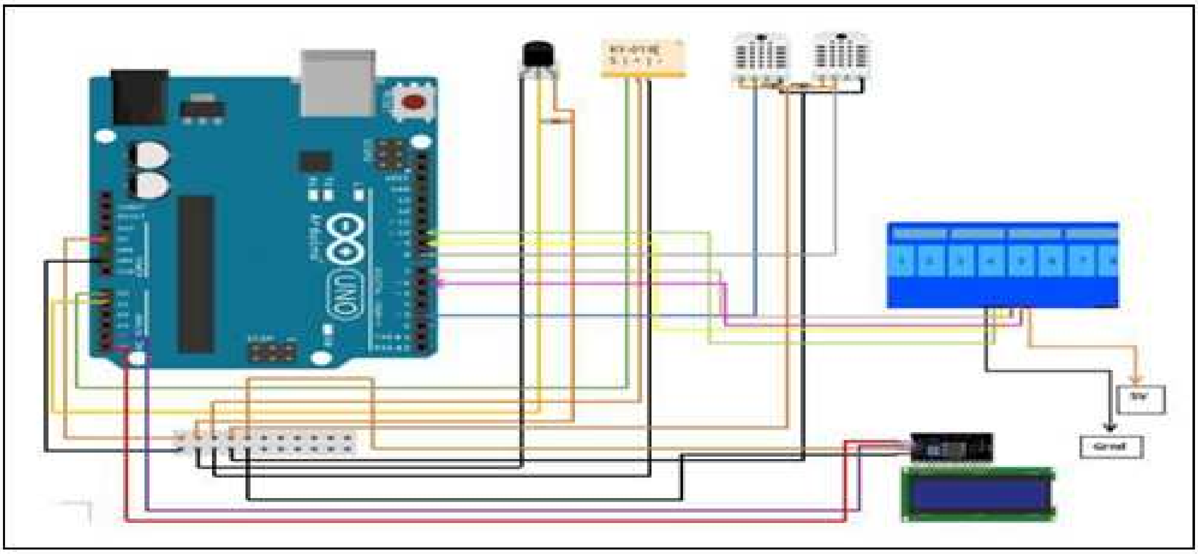

Fig. 3. Controls and monitoring system overview.

The humidity inside was a bit low because it's actually a closed environment, thus fresh air can't come in unless there is automation.

The temperature was high because temperature and humidity are inversely related to each other.

During the testing, without the system running, the humidity outside is always better than the humidity inside the system. The lowest humidity the system detected on the outside was in the range of 69-71. On the other hand, on the inside, the lowest humidity was in the range of 51-53. Fig. 10 presents the humidity inside varying through time with the system.

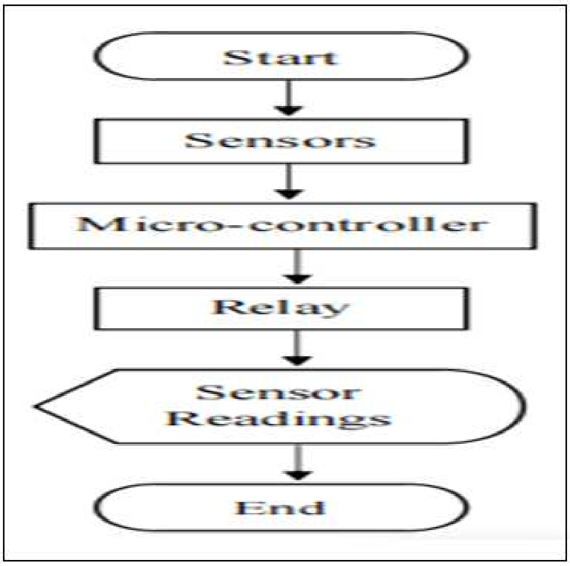

Fig. 4. General algorithm.

During the actual testing, the fan turned on during the time that the humidity outside was better than the inside, making the humidity on the inside and outside equal. So, during the testing, the fan was the one that turned on first.

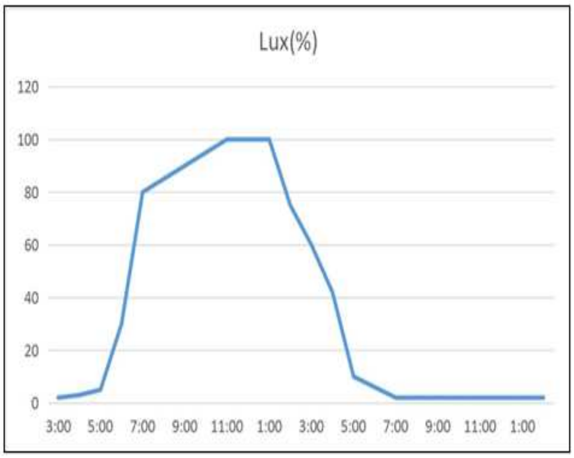

Fig. 5. Actual Light (lux) intensity without an automatic control.

During the one-day testing as shown in the figure, it was only four (4) hours and minutes more that the humidity was below 70%, so the humidifier in the system only worked on those hours. Unlike the fan, the fan operated for ten (10) hours during the day.

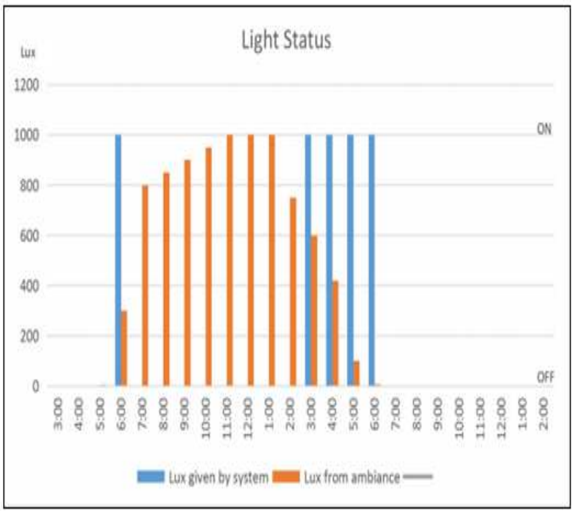

Fig. 6. Actual Light (lux) Intensity with automatic control.

As seen in the graph, between 9 AM and 6 PM, the humidity was not manipulated because both the fan and humidifier were turned off being because the temperature outside and in the inside are equal and not lower than 70%. Figs 11 & 12 present both the humidifier and fan testing set-ups.

DS18B20 water sensor testing

Fig. 13 below shows the graph representing the water temperature varying through time without the system. In Fig. 14, the water temperature varied through time with the system. During the actual testing, as shown in the graph, the temperature was fluctuating and not kept constant but still in the range of 27 to 32°C.

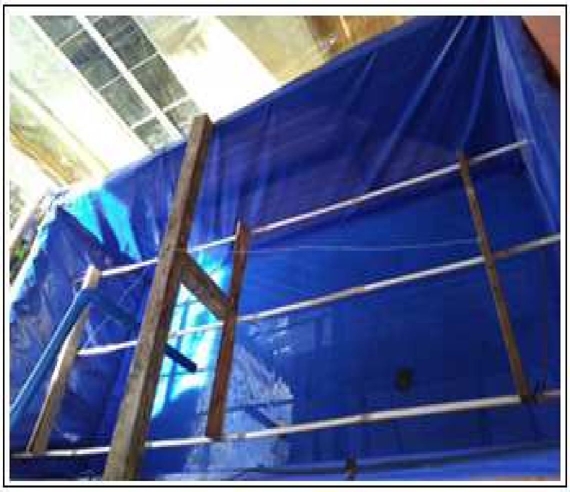

Fig. 7. Light Strips' Layout.

The temperature did fluctuate because the heater was programmed to turn on when the temperature would be below or equal to 27 °C and automatically would turn off when it reaches 32°C. As presented, the temperature did decrease and was not constant but still it did not go below or above the required temperature. Fig. 15 shows the setup.

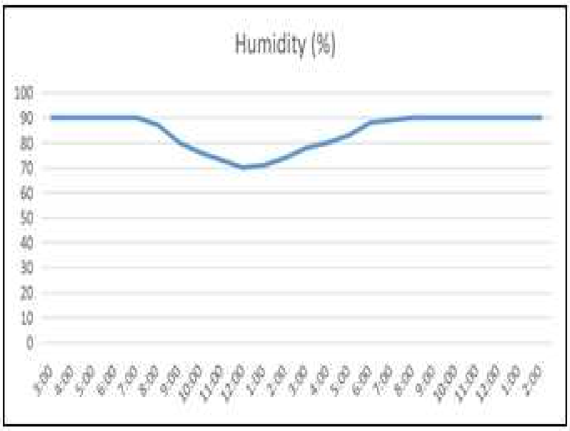

Fig. 8. Actual Humidity Outside.

Calibrating KY-018 sensor

In the calibration, both the sensor and the lux meter (reference) were placed in the same area. A constant light source was set up above the sensors. In this way, there is an assessment to be observed whether the sensor value and control company (reference value) have differed on numbers. A certain value can be changed on the program to make the sensor reading more precise. That certain value is changed until the two sensors and the control company have the same reading. Several trials were performed to attain the same reading for each sensor and reference value. Table 2 presents the percentage error of KY-018 sensor during the conduct of several trials.

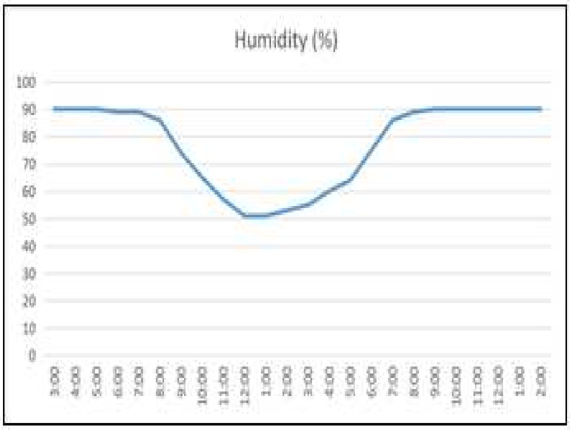

Fig. 9. Actual Humidity Inside without automatic control.

The calibration of DHT22 sensor was done by placing the two DHT22 sensors and the control company (reference) in the same area. A counting device was set up such as a stopwatch to count the number of times per calibration. After a minute, it can be assessed whether the sensor value and control company (reference value) have differed on numbers.

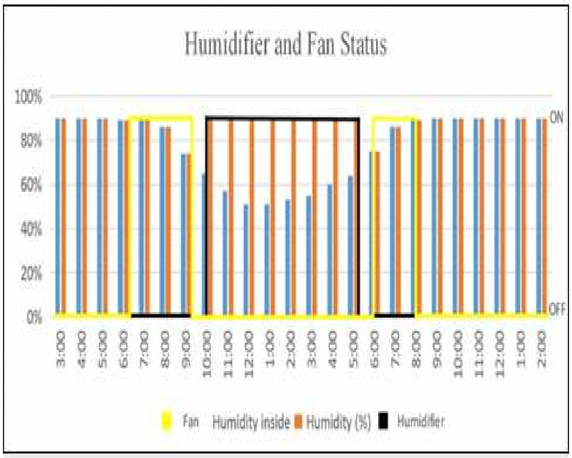

Fig. 10. Actual Humidity (Inside with automatic control).

A certain value can be changed on the program to make the sensor reading more precise. That certain value is changed until the two sensors and the control company have the same readings. Several trials were conducted to attain the same reading for each sensor and reference value. Table 3 above presents the results from several trials performed.

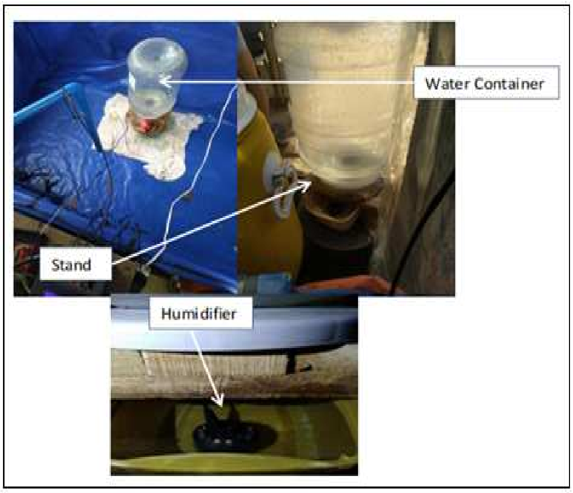

Fig. 11. Humidifier Testing and Placement.

Calibrating the DS18B20 sensor

The calibration was done by placing the sensor and the control company (reference) in the same area. A stopwatch was used to count the number of times per calibration. After a minute, it can be observed whether the sensor value and control company (reference value) have differed in numbers.

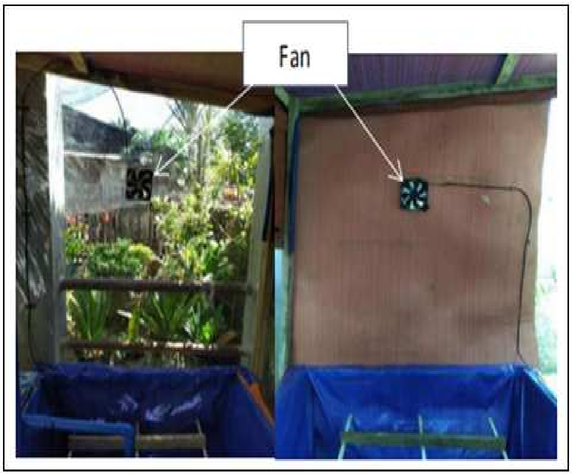

Fig. 12. Fan Testing and Placement.

A certain value can be changed on the program to make the sensor reading more precise. That certain value is changed until the two sensors and the control company have the same readings. Several trials were carried out to attain the same reading for each sensor and reference value. Table 4 shows the result of the calibration of the sensor.

Long-term performance evaluation of the system

Sensor readings were evaluated during the first day. The table readings (Table 5) were based on the reading of the sensors at 12 PM. This is because all the loads were running during this time and giving constant readings throughout. If the testing is done when the loads are not working, data may vary through the weather and the data cannot be varied from the first day till recent.

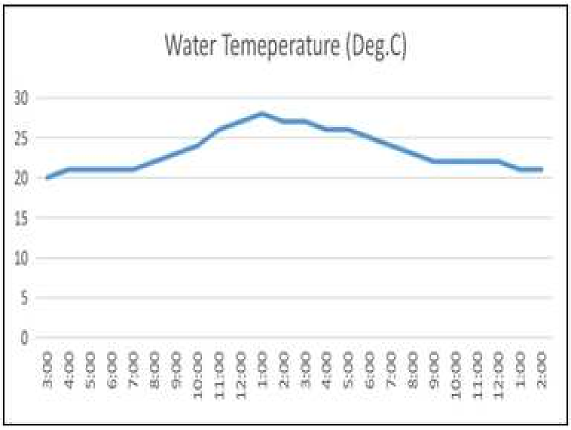

Fig. 13. Actual Water Temperature (☐) (without automatic control).

The system's sensors depreciated in their sensitivity based on the following values in the table. Three weeks passed, and the humidity sensor's sensitivity dropped 0.334482%. So theoretically, the system's humidity will drop 2.82% in six months. After which, it can be advised to do re-calibration if the sensor reaches a 5% error to restore sensitive reading.

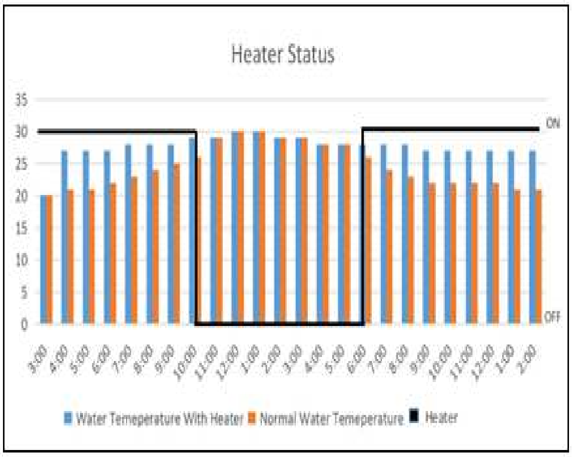

Fig. 14. Actual Water Temperature (☐) (with automatic control).

So theoretically, the system's humidity system will drop 2.10% in six months. It can also be observed that the water temperature sensor's sensitivity dropped 0.3717472%. As such, the system's humidity will drop by 3.17% in six months. Moreover, the sensor's lux sensitivity dropped 0.5%. Thus, the system's lux value will drop 4.28% in six months. If the sensors would reach 5% error, it is advised to conduct re-calibration to restore sensitive readings.

Dissolved oxygen in the System

Aquatic animals need a sufficient amount of oxygen for them to live and survive. A low level of oxygen means a low level of dissolved oxygen in the system. In the system, water aeration is present to produce oxygen, particularly, dissolved oxygen in the water. Dissolved oxygen (DO) was proven to be present and sufficient in the system. This was measured by the use of a dissolved oxygen meter applied in every part of the pond. Data are shown in Table 6 below presenting DO.

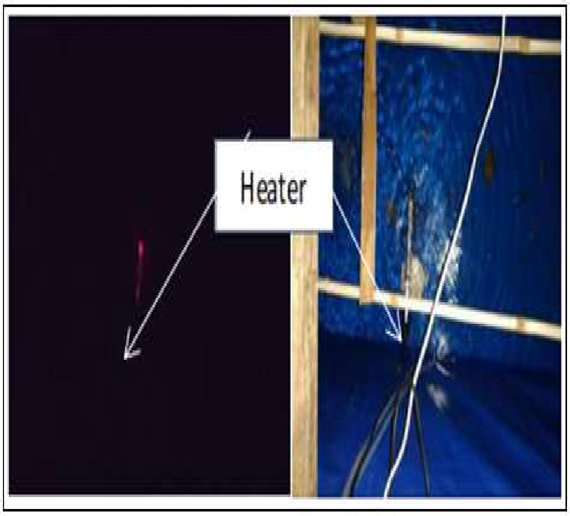

Fig. 15. Heater testing and set-up.

Growth development of red tilapia

The growth development of Red Tilapia is shown in Table 7 below. On the first day, the fish was measured and weighed. On the first day, the fish weighed 7.6 grams with a length of 2.75 cm. After three weeks, the fish weighed 20 grams and its length was 4 cm. The fish grew 0.48 gram each day and 0.05cm in length each day. The system sustained the sensitive Red Tilapia for five days and has achieved enough parameters for the fish.

In this study, control and monitoring functionalities in an automated small-scale aquaculture system were assessed at which the system's light intensity, water temperature and humidity were being monitored and evaluated. The controls of the said system were able to maintain proper light intensity, water temperature, and humidity. Water aeration also provided enough dissolved oxygen into the system.

It can be recommended to consider other water quality parameters in the system such as pH, oxidation-reduction potential, salinity, water hardness, conductivity, among others. It can be recommended to provide more water heaters for fast water heating in the system. And if the system is being applied to a naturally hot area, a cooling study or assessment may also be made.

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