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Development of an IoT-based Intensive Aquaculture Monitoring System with Automatic Water Correction

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Abstract: Due to the depleting stocks of fish in the market, there have been an increased interest in aquaculture. However, raising fishes in an Intensive Aquaculture System results on a low-quality fish or even fish kills as fishes are being cultured in artificial tanks and cage systems, not on their natural habit. This paper presents a water quality monitoring system with automatic correction to monitor and maintain vital water quality parameters essential for fish growth, such as temperature, potential hydrogen (pH) level, oxidation-reduction potential, turbidity, salinity, and dissolved oxygen to achieve optimum yield using Arduino and Raspberry Pi 3B+ through LoRaWAN IoT Protocol. The system uses sensors, microcontrollers, and a web application for acquiring and monitoring data of six different water quality parameters and are maintained in a desired level optimal for fish growth using aquarium heater, motor for sodium bicarbonate distribution, solenoid valve and water pump that serves as correcting devices. The proponents measured the system's efficiency and reliability through monitoring two intensive aquaculture setups – controlled and conventional setup. From the data gathered, the controlled setup greatly increased efficiency, reduced the work of fish farmers, avoided fish kills, and surpassed yield quality of the conventional setup.

Keywords: aquaculture, Arduino, Raspberry P, LoRaWAN, water temperature, pH level, oxidation-reduction potential, turbidity, salinity, dissolved oxygen

1. Introduction

Aquaculture is one of the most important and fastest rising industry for animal food production globally and is the principal contributor in human consumption in terms of aquatic animal food [1]. As fish cultured in aquaculture system uses the water in artificial tank to live, feed, grow, and excrete waste, the water quality easily declines that can affect its growth and health. Water quality identifies to an excessive degree the achievement or disappointment of fish farming. Hence, water quality is a significant factor in aquaculture operations guaranteeing the health of any aquaculture system [2]. Maintaining the water quality level in the ideal range enhances fish growth rate and reduces the incidence of fish diseases [3]. Among the essential water parameters to monitor and maintain are temperature, potential hydrogen (pH) level, oxidation-reduction potential, turbidity, salinity, and dissolved oxygen.

Fish growers depend on testing using manual means to monitor the state of several quality parameters of water. However, testing using manual approach is consumes time and as water quality changes continuously, it gives inaccurate results. Therefore, up-to-date technologies should be used to overcome this problem in aquaculture [4]. Mechanization of aquaculture setups will permit these subsequent advantages: (1) production nearer to market demand (2) enhance guidelines and directive with regards to the environment (3) lessen disastrous losses (4) minimize environmental control (5) reduce the charge of production (6) improve the quality of aquatic goods [5]. Furthermore, development in the aquaculture industry provides affordable aquatic animal food and is beneficial to industry economics to balance the losses in international trade [6].

The objective of this paper is to develop an aquaculture system that monitors and automatically corrects essential water quality parameters to improve fish growth rate. The

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study specifically aims (1) to develop an intensive aquaculture system that should monitor the temperature, pH level, oxidation-reduction potential, turbidity, salinity, and dissolved oxygen of the water and automatically turns ON/OFF the correcting devices, (2) to implement an Internet of Things (IOT) structure to access the automated aquaculture system through an Internet-based application that displays the status of the aquaculture setup, exhibiting the numerical values of the vital water parameters and the average length and weight to determine the growth of the fishes, and (3) to determine the system's efficiency and reliability and the difference of the growth rate of the fishes between the automated aquaculture system and the conventional setup.

The system focuses on monitoring and automatic correcting of water temperature, pH level, oxidation-reduction potential, turbidity, salinity, and dissolved oxygen. It utilizes sensors, microcontrollers, LoRaWAN, and correcting devices. Pre-programmed in the microcontroller are the threshold values for the six different quality parameters of water. Improvised correcting devices are developed using motor connected to microcontroller, water pump, heater, water bottle and drum. The water correction focuses on water replacement for stabilizing the water quality and adding of sodium bicarbonate solution for pH level. Through this, the water is set to an optimal range ideal for fish growth without exposing the fishes to various chemicals that may affect their health. Moreover, this method is a lot cheaper and easier to use for fish farmers. The data acquisition of sensors is only once per day and is set to occur at a specific time in the day while the correction takes place once the data acquired are not on the desired range optimal for fish growth. This study is restricted in culturing one species namely Nile Tilapia (Oreochromis Niloticus) in an Intensive Aquaculture system. Tilapia is a fast-growing fish and is tolerant to different aquaculture environments. Because of its growth rate, low production cost, and is affordable in the market, Nile Tilapia is being cultured in every method from extensive to intensive aquaculture system. They only have 5 basic needs: (1) food (2) light (3) room to Swim (4) oxygen and (5) clean water.

2. Related Works

An aquaculture system of De Belen et al. [7] developed an aquaculture system that uses three parameters namely: pH, temperature, and flow rate. These three parameters' correlation were computed, and experiments showed that "the pH has inversely proportional to temperature, but flow rate has no effect on the pH and temperature."

In Nagayo et al. [8], an aquaponics (a combination of aquaculture and hydroponics) [9]-[11] system with water recirculating part, Arduino-based control and monitoring part, GSM shield and NI LabVIEW, solar energy conversion system, and cooling and heating systems was designed for plant and fish growth. Meanwhile in [10] and [11], their aquaponics system utilized an Ion-Sensitive Field Effect Transistor (ISFET) as a pH device for optimum growth of plants and fishes. The superiority and efficiency of the ISFET-based pH device compared with the typical glass-electrode pH meter was proven through various experiment and testing its performance for evaluation. An aquaponics system which was proposed in Murad et al. [12] was developed that used temperature sensor, pH sensor, water sensor, servo, peristaltic pump, solar, liquid crystal displays (LCD), and GSM module water monitoring of aquaponics. The data is displayed through LCD and a notification is sent via GSM module. Fish farming and tracking control system of Gao et al. [13], developed a system to control and supervise water quality treatment equipment for fishpond. It also includes a predicting process for managing water quality automatically with the breeding and selling of freshwater fish being tracked. This study uses integrated sensor assembly, GUI, QR code and LoRa wireless transmission technology. In Daud et al. [14], an aquarium setup with pH level monitoring and fish feeding system in android application was developed using analog pH sensor, Arduino MEGA, NodeMCU controllers and Liquid Crystal Display (LCD). To use the smartphone as controller to control the operation of fish feeding, the NodeMCU utilized Wi-Fi mode of communication. The data acquired from the sensor is displayed through LCD.

According to Wu et al. [15], the use of smartphones or mobile devices in IoT applications such as agriculture can reduce energy consumption in terms of data generation, lessen manufacture and deployment cost, and is considered environmentally friendly as it reduces the number of deployed sensors. In Atat et al. [16], facilitating Internet of Things in different applications connects different cyber physical systems (CPS) which are systems that comprises the interrelated physical objects and a computer program or application. This aid implementing their transfer of information. Today's technologies make receiving the data from CPS an easiest duty since low cost smart sensors are available anywhere.

The study of [17] further discussed the efforts done to measure water quality using sensors. It cited [18] where sensors are deployed to monitor underwater environment parameters e.g. pressure, water level, water flow, and temperature. Citing the study of [19], [20] stated the study's proposed device that determines possible sources of pollution such as agricultural activities by water quality monitoring. [21] stated that information and communication technologies could boost agricultural productivity through knowledge and information extension and dissemination. With these in mind, one of the United Nations Sustainable Development Goals (SDG) which is Sustainable Agriculture (SDG 2) will be achieved.

Most of prior works concerning aquaculture systems and fisheries only considered to monitor water quality parameters limited to only few rudimentary standards. To further improve the study, it is also important to ponder on some of the other parameters that greatly affects the growth and quality of the fishes thus, the proponents considered using six different water quality parameters. Also, the incorporation of automatic correction for the parameters suggests for a lesser work and stress not just for the owners but also for the fishes itself which some of the existing aquaculture setups in various studies didn't have. Profound studies on the matters regarding fish growth proves stress as one of the biggest factors that affects the growth of the fishes which is why the lack of direct contact with the fishes warrants for a healthier fish.

3. METHODOLOGY

A. System Architecture

This project is mostly focused on maintaining and correcting vital water quality parameters of the aquaculture setup for desired result. The automatic correction initiates once undesired range are not met. In this paper, the vital water quality parameters which were taken into account are temperature, potential hydrogen (pH) level, oxidation-reduction potential, turbidity, salinity, and dissolved oxygen.

Figure 1 shows the System Architecture of the study. Two microcontrollers were used. The six water parameter sensors are DFRobot Gravity: Analog Dissolved Oxygen Sensor, Gravity: Analog Turbidity Sensor, Gravity: Analog Electric Conductivity Sensor, Waterproof Temperature Sensor DS18B20, DFRobot Industrial Analog pH Sensor, and DFRobot ORP Analog Meter. The said sensors and automatic water corrector are connected to Arduino Mega. The threshold values for the water quality parameters are pre-programmed in the microcontroller to test whether the data acquired satisfy the desired values. When the range aren't met, correcting devices will automatically activate.

For the data transmission, the Arduino Mega reads the analog data and sends it to the Raspberry Pi. From here, the data are sent to the database via Long Range Wide Area Network (LoRaWAN) IoT Protocol and displayed to the Web Application.

B. Monitoring and Correction System

Figure 2 shows the overall setup of the study with controlled and conventional environment. To determine the status of the aquaculture system, temperature, potential hydrogen (pH) level, oxidation-reduction potential, turbidity, salinity, and dissolved oxygen sensors are placed in the aquarium. All the sensors are integrated into a small-box small box-like container to provide ease of use to the user making it adaptable to multiple environments given that it can be put properly since only a little part of the sensors can be submerged into the water.

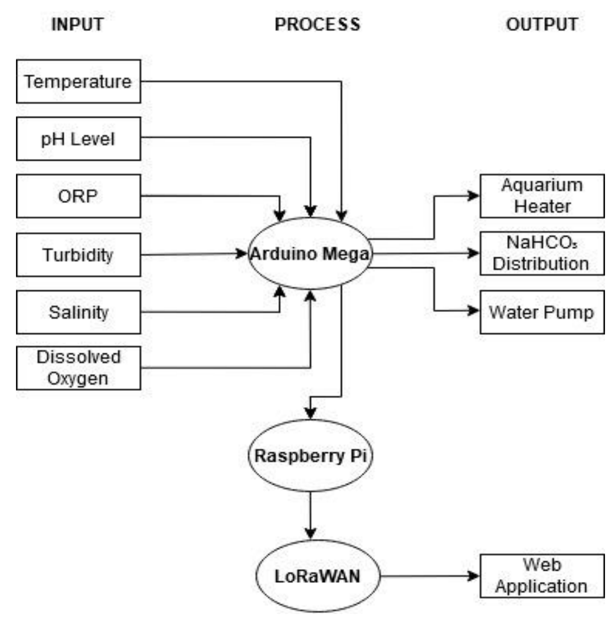

Figure 1. System Architecture

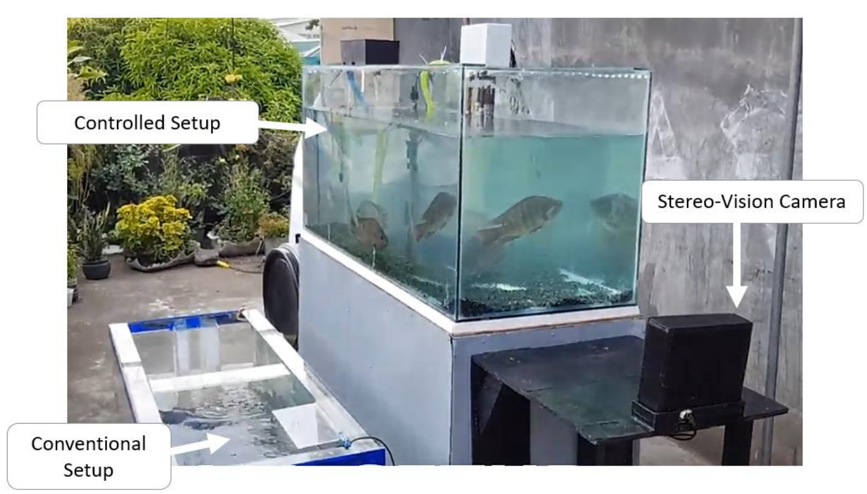

Figure 2. Conventional and Controlled Aquaculture System

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The values which are gathered from the sensors are sent to the Arduino Mega. When oxidation-reduction potential, turbidity, salinity and dissolved oxygen values are not on the ideal range optimal for fish growth, the water pump will be activated to change the water. When pH level is below the threshold value, the motor for sodium bicarbonate solution will be activated to distribute the solution. Both will be switched off when the obtained data falls within the threshold and aquarium heater will be placed inside calibrated to 28 ℃. The data are then transmitted to Raspberry Pi that will send it to the Web Application for monitoring via LoRaWAN IoT Protocol. An 868MHz LoRaWAN is used.The data transmission via LoRa modules is suitable for monitoring aquaculture setups as it reduces production cost and supports longer-distance communication.

The system can be applied to any environment as long as electricity is provisioned. For the water source, since nile tilapia is a type of fish that lives in fresh water and has a high tolerance, tap water can be used to replace the water in the setup given that it is treated with dechlorinate drops and vitamins and is stocked in a container for a minimum of 24 hours to dechlorinate.

C. Web Application

The TeamLapia web application, as shown in Figure 3, is made to consolidate all the data gathered and display the most recent status of water parameters and fish growth. It not just exhibits the status of the latest entries but also the numerical values for those said parameters including those that determine the growth of the fishes (no. of fishes, average length and weight). It is made possible through the use of PHP and JavaScript codes that transmits data from database to the UI as it keeps storing new data entries. The graphs and dynamic design of the application, on the other hand, is made using html, CSS and JavaScript scripts to make it more suitable for end users.

The page is divided into different sections as shown in Figure 4. The first panel shows the header that says “Fish Growth and Water Quality Monitoring System” which is what the study is all about. Upon scrolling along the page, it will show the panel that describes the three main functions of the study each presented with the appropriate icons. The third part of the application is where the status of the sensors can be seen. There are six clickable rectangular panels that represents the six different water parameters of the system. The last panel shows what is inside a parameter panel located in the water parameter sensors section. A brief description of the parameter is included together with the graph of the past values gathered by the sensor. Also, a part where you can see the current level/status of the parameter is included in the pane.

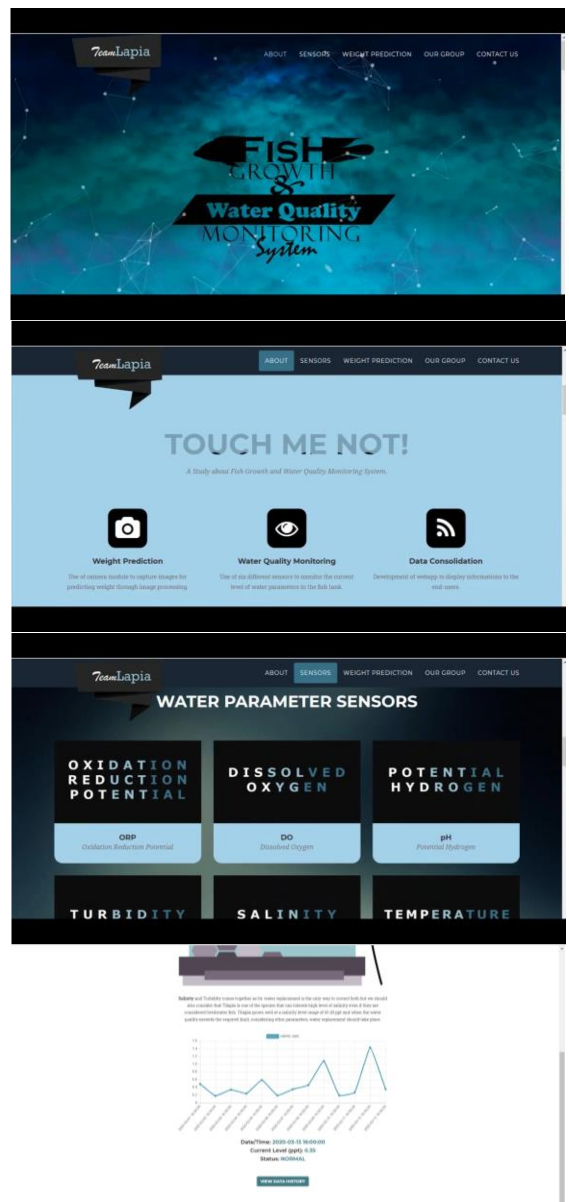

Figure 3. Web Application Interface

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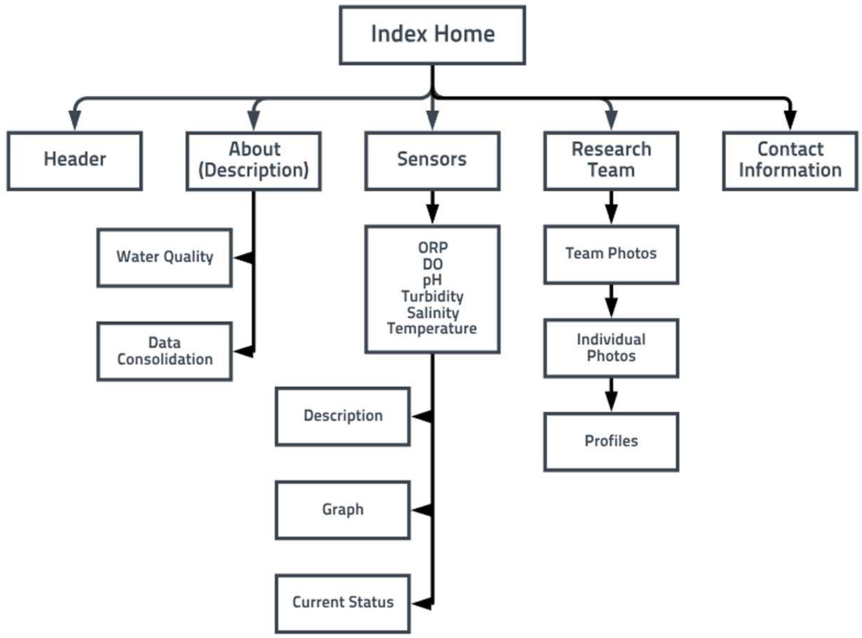

Figure 4. Web Application Structure Diagram

4. Results And Discussion

In the controlled system, temperature, potential hydrogen (pH) level, oxidation-reduction potential, turbidity, salinity, and dissolved oxygen were regularly monitored and corrected to provide an environment optimal for fish growth. For the conventional setup, the water is left unchanged and unchecked throughout the week.

Figure 5 shows the pH level for the controlled aquaculture setup. Whenever the reading goes beyond the threshold level, the system automatically corrects the water. The ideal pH level for Nile Tilapia is 6 to 9 (unitless).

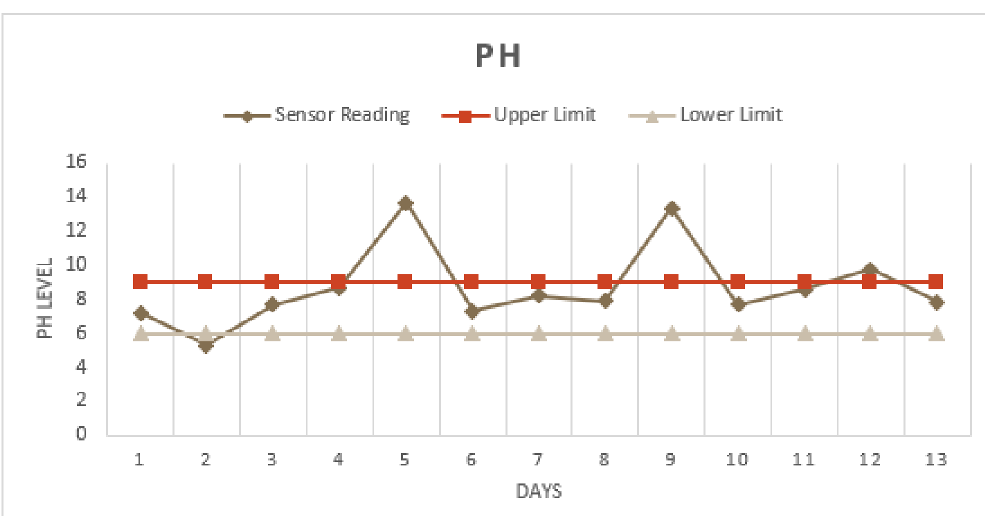

Figure 5. Potential Hydrogen Sensor Readings with Correction Response

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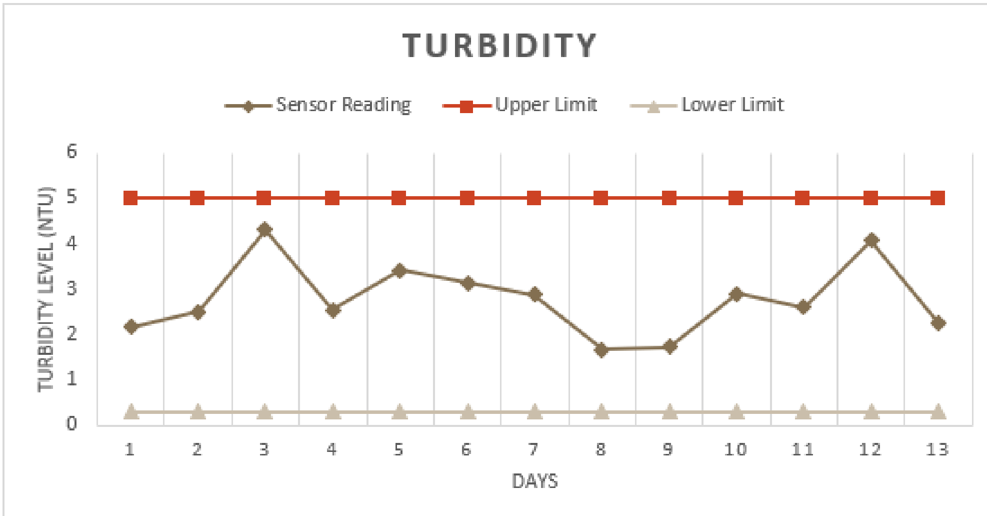

Figure 6. Turbidity Sensor Reasings with Correction Response

Figure 6 shows the graph of turbidity sensor readings for the controlled aquaculture setup. Whenever the reading goes beyond the threshold level, the system automatically corrects the water. The threshold limit of turbidity which fishes can tolerate ranges from 0.3 – 5 NTU.

Figure 7 shows the oxidation reduction potential sensor readings for the controlled aquaculture setup. The ideal value of ORP optimal for fish growth ranges from 150mV to 250mV.

Figure 8 shows the temperature sensor readings for the controlled aquaculture setup. Ideal water temperature for Nile Tilapia ranges from 25-27 °C. A water heater is used to prevent temperature from dropping.

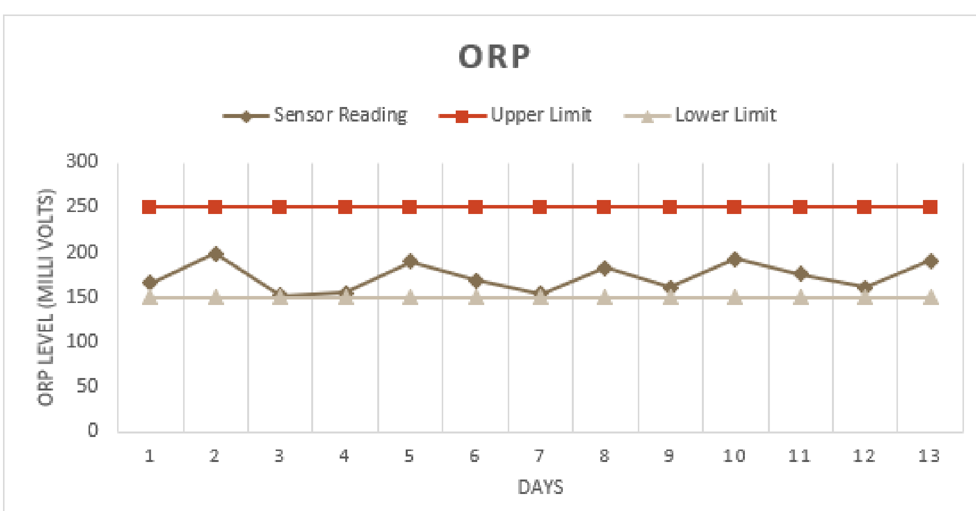

Figure 7. Oxidation Reduction Potential Sensor Readings with Correction Response

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Figure 9 shows the graph of salinity sensor readings for the controlled aquaculture setup. Nile Tilapia has a wide range of saltiness that they can tolerate, and they can perform better at salinities below 5ppt. It is reflected by the low level of salinity shown in the graph.

Figure 10 shows the graph of DO sensor for the controlled aquaculture setup. The ideal range for Dissolved Oxygen ranges from 1-2.5 mg/L. The oxygen level is being maintained in the system with the help of an aerator.

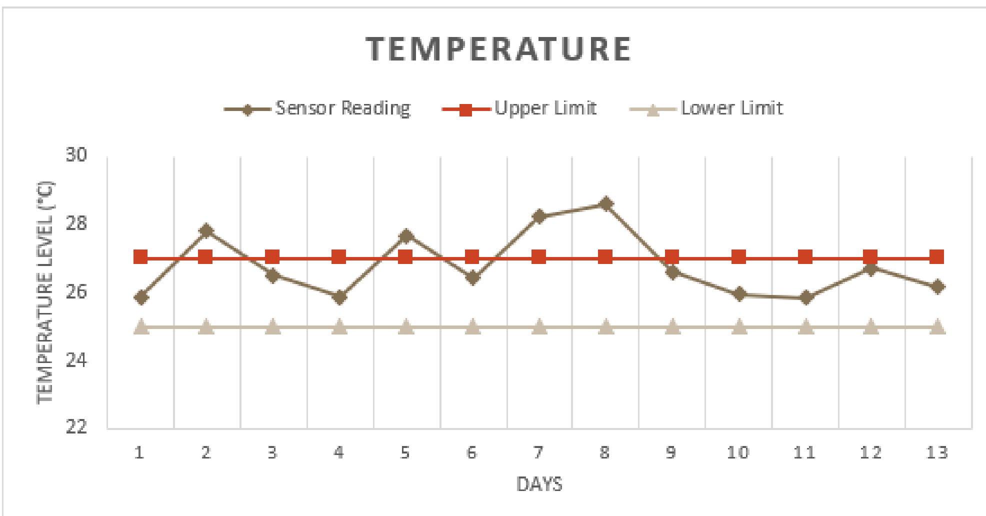

Figure 8. Temperature Sensor Readings with Correction Response

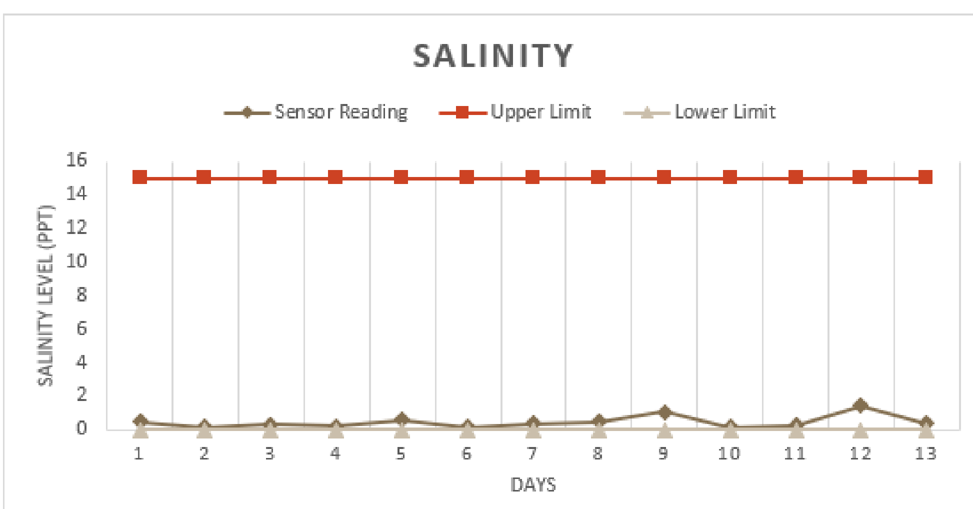

Figure 9. Salinity Sensor Readings with Correction Response

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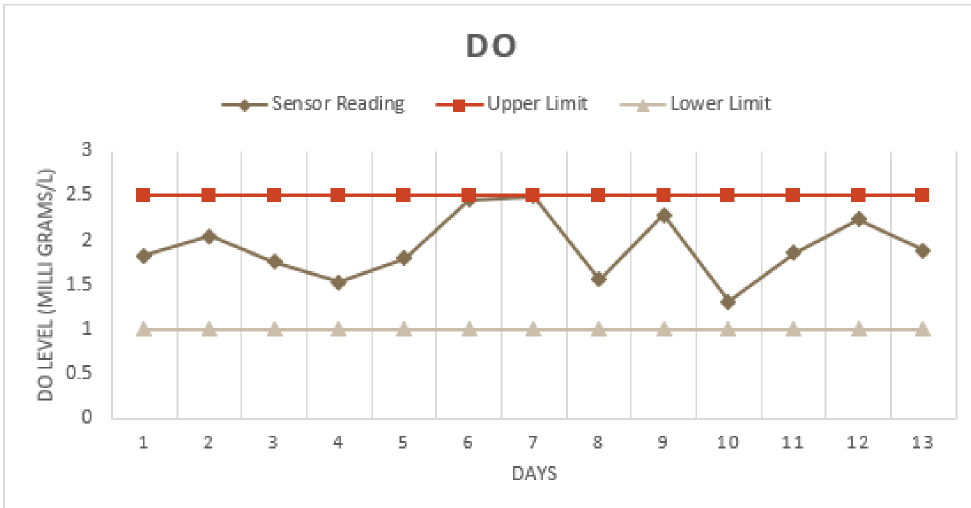

Figure 10. Dissolved Oxygen Sensor Readings with Correction Response

Figure 11 shows the mean (average) fish weight per week in both controlled and conventional aquaculture setups. Initially, the fishes' weight on both tanks are equal and the fishes' growth is monitored for two weeks. The highest average fish growth rate based on weight in the controlled system was 17g (from 24g to 41g) while the conventional system only obtained an average of 11g (34g to 35g).

As shown in Table I, the growth rate in the aquaculture setup is 30.70% each week and is more than the conventional setup's growth rate which has 20.76% growth rate per week. The controlled aquaculture setup improves the growth of the fishes in terms of weight by 46.88%.

TABLE I. FISH GROWTH IN EACH SETUP

Days Elapsed	Average Fish Weight (g)	
	Proposed Aquaculture Setup	Conventional Setup
0 (initial)	24	24
7 (week 1)	33	28
12 (week 2)	41	35

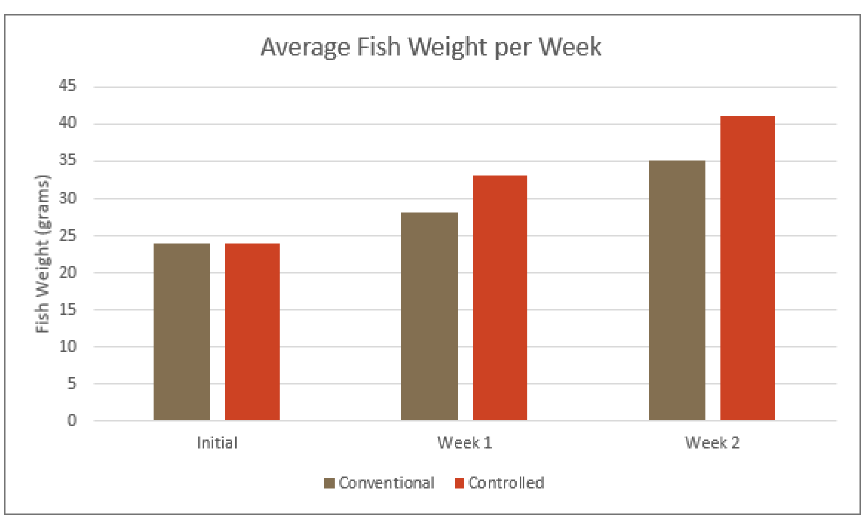

Figure 11. Controlled vs. Conventional Fish Growth measured every week

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5. CONCLUSION

The aquaculture environment was optimized for fish growth by constructing a monitoring and correction system. The controlled aquaculture system yields a higher growth and survival rate of Nile Tilapia compared with the conventional aquaculture setup.

For future work, this study can also be applied in providing optimal environment condition essential for growth of other aquatic animals in different aquaculture systems. An automatic feeding system is also advisable to prevent spoiling of water because of left-overs since it releases small amount of feeds at regular intervals instead.

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