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IoT-Based Automated Water Monitoring and Correcting Modular Device via LoRaWAN for Aquaculture

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Abstract: In the aquaculture industry, the slow growth of fishes and fish kills in fisheries are the problems encountered by every fish farmer. Water quality is a critical factor and must be monitored when culturing any aquatic organism; however, most of the fish farmers do not consider it since water testing and water sensors are costly and not user-friendly. In order to solve this problem, we have created an Internet of Things-connected modular device that will assist the local fish farmers via their smartphone using our application for real-time monitoring and setting up the device, and data storage. The modular device consists of different water sensors such as pH, water level, temperature, dissolved oxygen, total dissolved solids, oxidation reduction potential, and turbidity. These sensors, together with different actuators such as aerator, water filter, peristaltic pump, water pump, fish feeder, and heater will help monitor and correct the abnormalities in the water environment. The readings made by the proposed modular device were compared with the Bureau of Fisheries and Aquatic Resources-National Inland Fisheries Technology Center (BFAR-NIFTC) multimeter. A low percentage difference between their readings is below 2%, which is within the accepted value.

Keywords: Aquaculture, Modular, Internet of Things, Oxidation-Reduction Potential, Turbidity, Gateway, LoRaWAN

1. INTRODUCTION

The Philippines, covered by 2,257,499 km^2 total area of marine water, is the 6th in rank worldwide for fish and aquaculture production in 2008. In 2017, the Philippines' population was estimated to be 103 million. The percentage consumption of fishery products compared with the total intake is at 12.8%. This increase of fish consumption resulted to overfishing. Almost all seawaters within 15 kilometers of shore are overfished [1].

When culturing any aquatic organism, water quality is a critical factor and must be monitored. Different species require different optimal water quality. Significant water parameters such as dissolved oxygen (DO), carbon dioxide, temperature, pH, alkalinity, nitrogen, salinity, biological oxygen demand, and total suspended solids (TSS) can affect species' development, reproduction, and existence. These parameters may also be monitored based on the culture setup. Some of these are relatively stable and do not require continuous monitoring, but others such as DO and pH vary day-to-day. Establishing a routine water quality testing for a particular culturing environment is important to sustain the good quality of catches [2].

The aquaculture industry encounters problems like fish kills and slow growth of fishes. They occur when DO get depleted as a result of over stocking and overfeeding. Deterioration of water quality is a serious issue for aquaculture. About 50 river systems have no presence of living organisms because of pollution from humans, agricultural, industrial, and animal waste. About 90% of wastewater, which are settled in bodies of water, are not sufficiently treated. The Philippine Environment Monitor of 2014 stated that the release of wastewater has produced widespread polluted water. Water quality monitoring and surveillance are assigned to the Philippines' Department of Environment and Natural Resources - Environmental Management Bureau (DENR-EMB), but some of its regional offices do not have appropriate resources and capabilities.

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As a solution to the problem stated, we propose an aquaculture monitoring and correcting device via Android Internet of Things (IoT) application to automate the water monitoring and automatic correction of certain parameters. IoT is an interconnection of the Internet with various "things" e.g. sensors and devices which can improve and enhance their control and sensing capabilities through programming, computing, and analytical implementations.

2. Related Works

Various studies related to Water Quality Monitoring can be found. For example, a study by Guerrero and Fernandez [3] discussed the main problems and alarms in the aquaculture and water sector in the country. Water quality is one of the critical criteria for the growth and survival of freshwater and marine life but is often set aside by the aquaculture farmers due to the lack of resources for water quality testing. The Real-time Water Monitoring and Automation developed by Harun et al. [4] focused on different parameters such as temperature, pH and DO levels and interfaced with aerating and water supply pumps utilizing Arduino. The data were later sent to the preferred communication or gadget at a certain period of time through Internet. Simbeye and Yang [5] concentrated their study on temperature, dissolved oxygen, pH, ammonia, nitrates, salinity, and alkalinity that are the vital parameters needed to be monitored and regulated, since they directly affect animal's wellbeing, feed usage, growth rates and carrying abilities. A wireless sensor network (WSN) monitoring and control system was designed for this study. The studies in [6]-[8] used ISFET and glass electrode as water pH measurement devices for their aquaponics (a hybrid of aquaculture and hydroponics) setups.

The design of Smart Sensors for Real-time Water Quality Monitoring by Cloeta et al. [9] developed a system that can inform the user of the monitored water quality parameters in real time setting. It monitors the water flow, water temperature, pH, water conductivity and the oxidation-reduction potential (ORP) identifying different contaminants in water. Del Valle et al. [10] designed a project that emphasized the importance of water quality to the community, bodies of water, and marine species. It is a profiling buoy network that allows the government and nearby industries to monitor the water quality along Cabuyao River. The network can coordinate and send information to a main station that records the data for monitoring by the used of LoRaWAN technology, a point-to-multipoint networking protocol that uses LoRa modulation scheme, for its efficient and practical mode of data transmission.

Nocheski and Naumoski [11] focused on sustaining the maintainable setting of fishponds for particular fish types by doing the tasks quickly by an IoT-based system. The IoT system monitors temperature, light intensity and water level though sensors. It also used Arduino Mega2560 that analyzes the parameters and notifies the user of the sound and visual information. For the study of Saja et al. [12] the progression of IoT is applied and implemented for determining water quality through the use of Raspberry Pi and Arduino (as data processors and IoT servers), different sensors, smart phone camera, and an Android app.

The previous reference studies were analyzed to create an innovative device for water monitor and control considering some of their notable experimental results. Previous reference studies only covered monitoring for temperature, pH, DO and water level. Furthermore, most of their systems used only aerator and water pump for water abnormality correction. The latter study utilized wireless network (WSN) where sensor nodes were needed to be charged regularly and the communication speed of a wireless network was comparatively slower than a wired network. In our work, the system could monitor seven or more water parameters and we used specifically the pH level, ORP, temperature, dissolved oxygen, total dissolved solids (TDS), water level, and turbidity; it was integrated with peristaltic pump, water filter, aerator, and heater to automatically correct the certain abnormalities in the water. Moreover, a mobile application was developed using Android Studio that displays the real-time water parameter graph readings via LoRaWAN. All shortcomings of the related studies were considered and utilized for advancing the Water Monitor and Correct System.

3. Development Of The Water Monitoring Device

The outline of the AQUAlity Device, a water monitoring and correcting device, could be simplified into a block diagram as shown in Figure 1. The proposed aquaculture system is composed of the following four sections: water parameter monitoring system, the relay drivers for correction, mobile application, and IoT-LoRaWAN for transmission. The water monitoring sensors transmits the data to Packetduino, then through the LoRa module connected to the Packetduino, a LoRaWAN compatible microcontroller, then to a Gateway that connects to our AQUAlity application to view readings real-time, while the relay drivers function as switches programmed depending on the readings from the water monitoring sensors to operate the actuators.

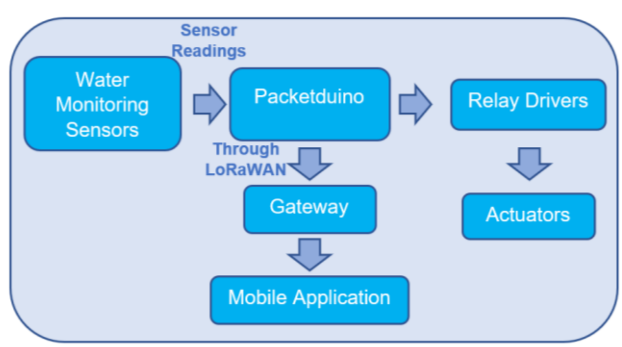

Figure 1. Simplified System's Block Diagram

Figure 2 shows the block diagram of the whole system of the AQUAlity Device. The main supply is a 220V AC Voltage that is converted to +5V DC Supply using a DC Buck Converter; +5V DC is then supplied to Packetduino where sensors are attached. The gathered data from the sensors is sent to the Packetduino, then the actuators are operated based on the conditions programmed to the Packetduino through Solid State Relays and Metal–Oxide–Semiconductor Field-Effect Transistor (MOSFET) Drivers. Water Filter, Aerator and Additional Correctors is supplied with a 220V AC Supply and the Peristaltic

Buffer, automatic feeder and additional correctors are supplied with +12V DC supply from the DC buck converter. While the sensors and actuators are operating, the Packetduino is transmitting data gathered via LoRaWAN through a Gateway to a Network Server then to the AQUAlity Application.

Sending and receiving data between the system and the Android application are made via LoRaWAN. The readings obtained by the sensors connected to Packetduino can be monitored through a smartphone with the help of IoT-LoRaWAN.

A. *Water Monitoring Sensors*

Upon consultation with Bureau of Fisheries and Aquatic Resources-National Inland Fisheries Technology Center (BFAR-NIFTC) upon consultation, the necessary parameters to be considered in water monitoring are the following:

- pH Sensor: used to measure the acidity or alkalinity of water and it is commonly used for many applications such as aquaponics, aquaculture, and environment water testing.
- Oxidation-Reduction Potential Sensor: a combination sensor with a measuring electrode and a reference electrode.
- Water Temperature Sensor: used to measure the temperature of the water.
- Dissolved Oxygen (DO) Sensor: measures the amount of DO in the water. Higher DO concentration means better water quality.
- Water Level Sensor: a sensor that determines the water level.
- Turbidity Sensor: detects suspended water particles by determining the amount of light transmittance and rate of scattering which varies with the number of TSS.

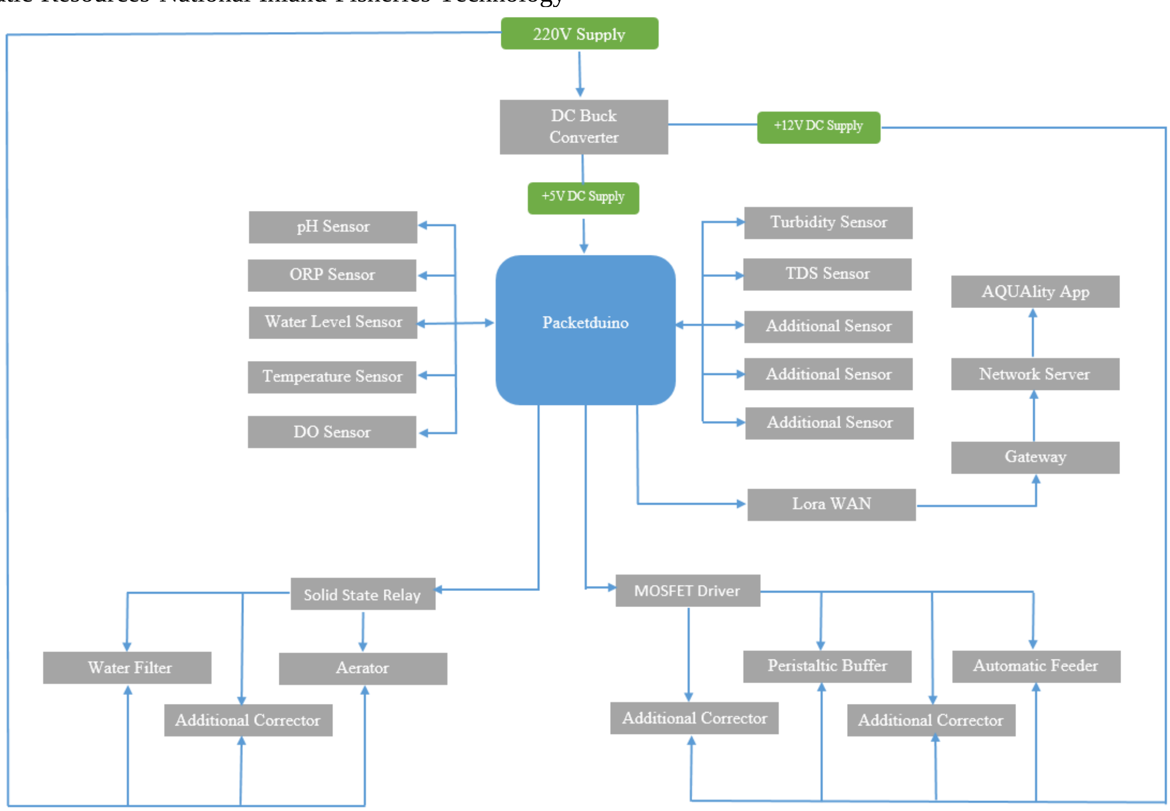

Figure 2. The Overall Block Diagram of the Proposed Aquaculture Monitoring and Correcting Device

- Total Dissolved Solids Sensor: determines the cleanliness of the water by measuring how many dissolved solids (mg/L) in the water.

B. Actuators

The following actuators used can adjust and correct the following parameters (up to 10 additional actuators may be connected):

- Aerator: a 220VAC, 300W device that provides proper aeration in the aquarium to allow fishes to breath properly. It brings water and air in close contact to eliminate dissolved gases such as carbon dioxide.
- Heater: a 220VAC, 18W actuator which keeps the water temperature at a stable and desired level.
- Peristaltic Pumps: two 12VDC, 10W actuator that automatically pump different fluids.
- Water Filter: a 220VAC, 18W actuator which can extract excess food pellets, free-floating solids, hazardous chemicals, and the fish's excrements from the water.
- Motor pump: a 12VDC, 5W device delivers water to fish tank

C. The Hardware

Figure 3 shows a box type chassis design of the device. The chassis has a dimension of 250 mm (length) × 190 mm (width) × 230 mm (height) and features a snap fit locking mechanism. The two tubes on each side function as a floating device. The LED lights on the front function as an indicator of water temperature, with green for low temperature, yellow for normal temperature, and red for high temperature. The pipes on each side are outlets for the sensor.

The fabricated Printed Circuit Board (PCB) containing the Packetduino (an Arduino clone made by Packetworx) and the sensor modules is highly secured in the watertight chassis. Custom-built floaters are placed both sides to maintain the balance of the device on the water and to get more accurate readings. The PCB prototype measures 50.8 mm × 50.8 mm PCB for the 3 LED indicator and two (177.8 mm × 152.4 mm) PCB where Packetduino, sensor modules, DC-DC buck converter and relays can be mounted/unmounted. Placement of the sensors and power supply devices are carefully considered to avoid electromagnetic interference (EMI), crosstalk, and the noisy and high impedance lines.

Figure 4 shows the placement of sensor modules, Buck converter and microcontroller on the PCB. Sensor modules are placed on the both left and right of the PCB. Buck converter at the bottom right and microcontroller at the middle between the sensor modules.

Figure 5 shows the placement of power MOSFET switch (MOS) and solid-state relay (SSR) on the PCB. MOS are placed at the top part of the PCB and SSRs on the side.

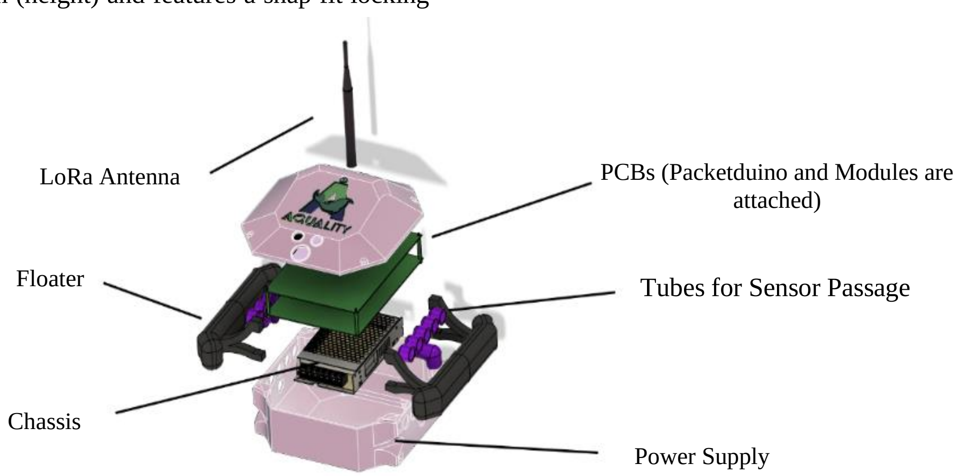

Figure 3. The Device and Its Parts

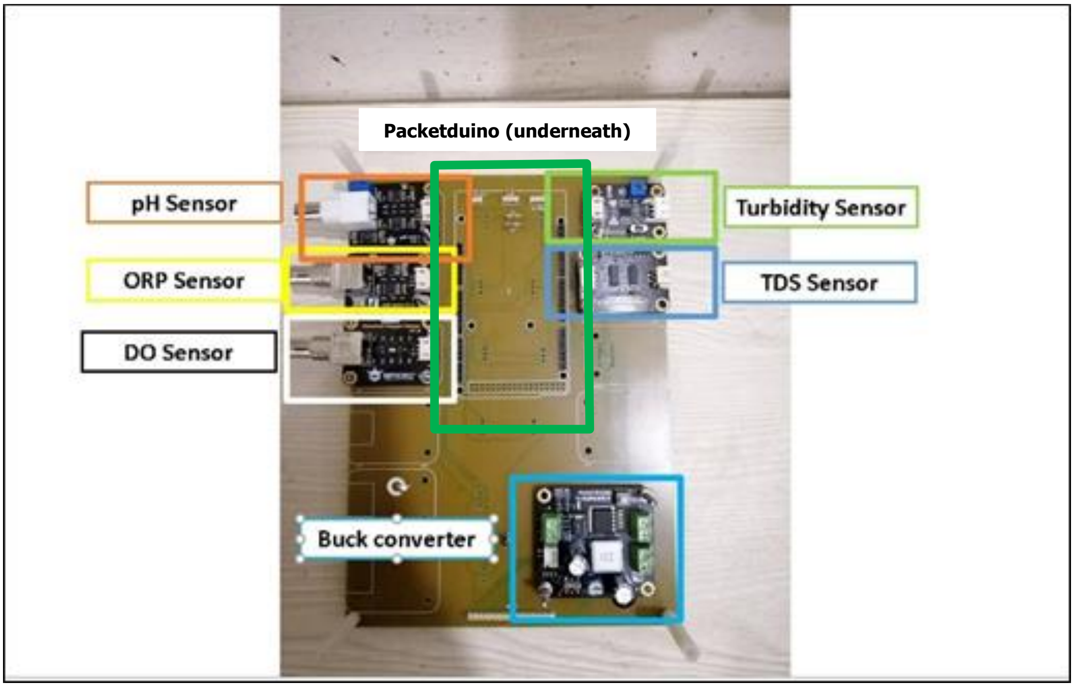

Figure 4. MOS and SSR Placement in the PCB

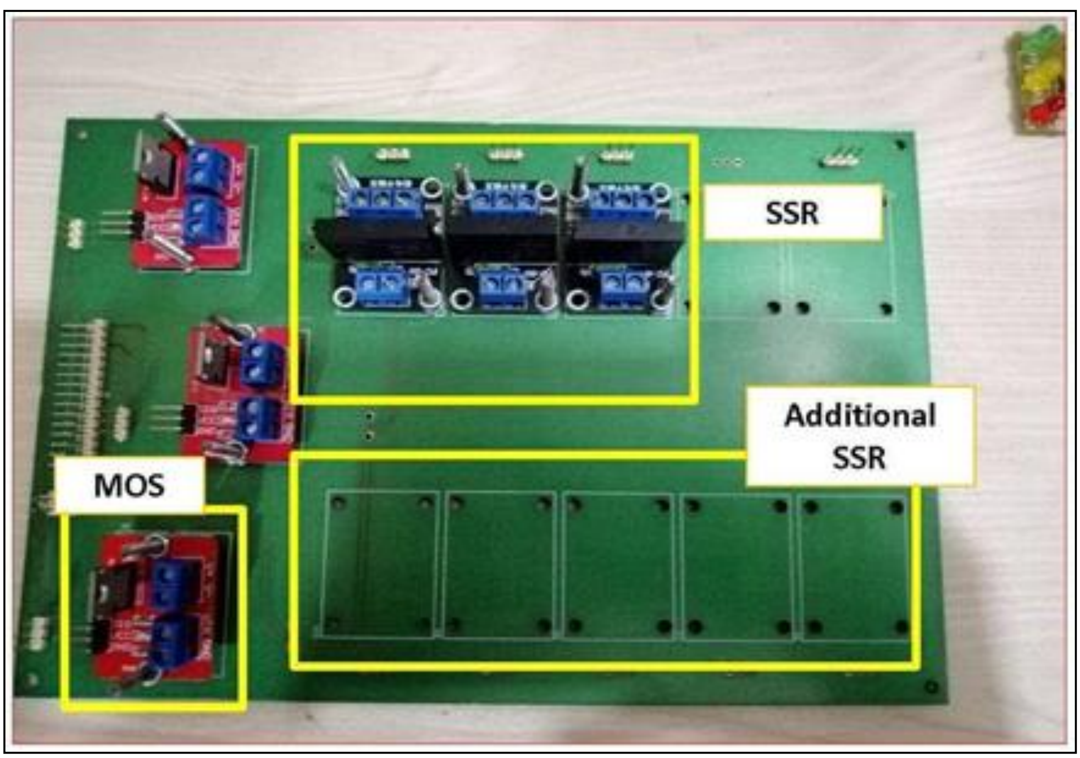

Figure 5. Sensor Module Placements in the PCB

D. Software Development

Arduino IDE (Integrated Development Environment) was utilized in the development of the software section of the automated aquaculture system. Electrical signals gathered from different sensors like pH, temperature, turbidity, DO, water level, TDS, and ORP sensors are converted by the microcontroller´s Analog to Digital Converters.

The AQUAlity App was an Android application developed using Android Studio inventor, it serves as the graphical user interface of the system, presenting the different determined water quality parameters. The data are transmitted through the IoT gateway to the mobile application with the help of the LoRaWAN module. The application enables users to monitor real time.

Figure 6 shows the overall data gathering and correction system flowchart. There are different threshold values for each sensor. The threshold value for the turbidity is 5-10 NTU (Nephelometric Turbidity unit, the unit used to measure the turbidity of a fluid or the presence of suspended particles in water. When the gathered data is greater than 10 NTU, the water pump will turn on to recirculate the water and replace it. For the TDS, the threshold value is 13.6 mg/L. When the gathered data is greater than the 13.6 mg/L, the water pump will turn on and use the filtration system to reduce the amount of TDS in the water. The threshold value for ORP is 150mV to 250 mV.

When the gathered data is greater than the threshold value, the water pump will turn on to recirculate the water and reduce the oxidation reduction potential. The threshold value for the water level is 1 m. When the gathered data is less than 1 m, the water pump will turn on to increase the level of the water. The threshold value for the dissolved oxygen is 6 to8. When the gathered data is less than 6, the peristaltic buffer pump will release calcium carbonate ($CaCO_3$). The threshold value for the dissolved oxygen is 3 to 12 mg/L.

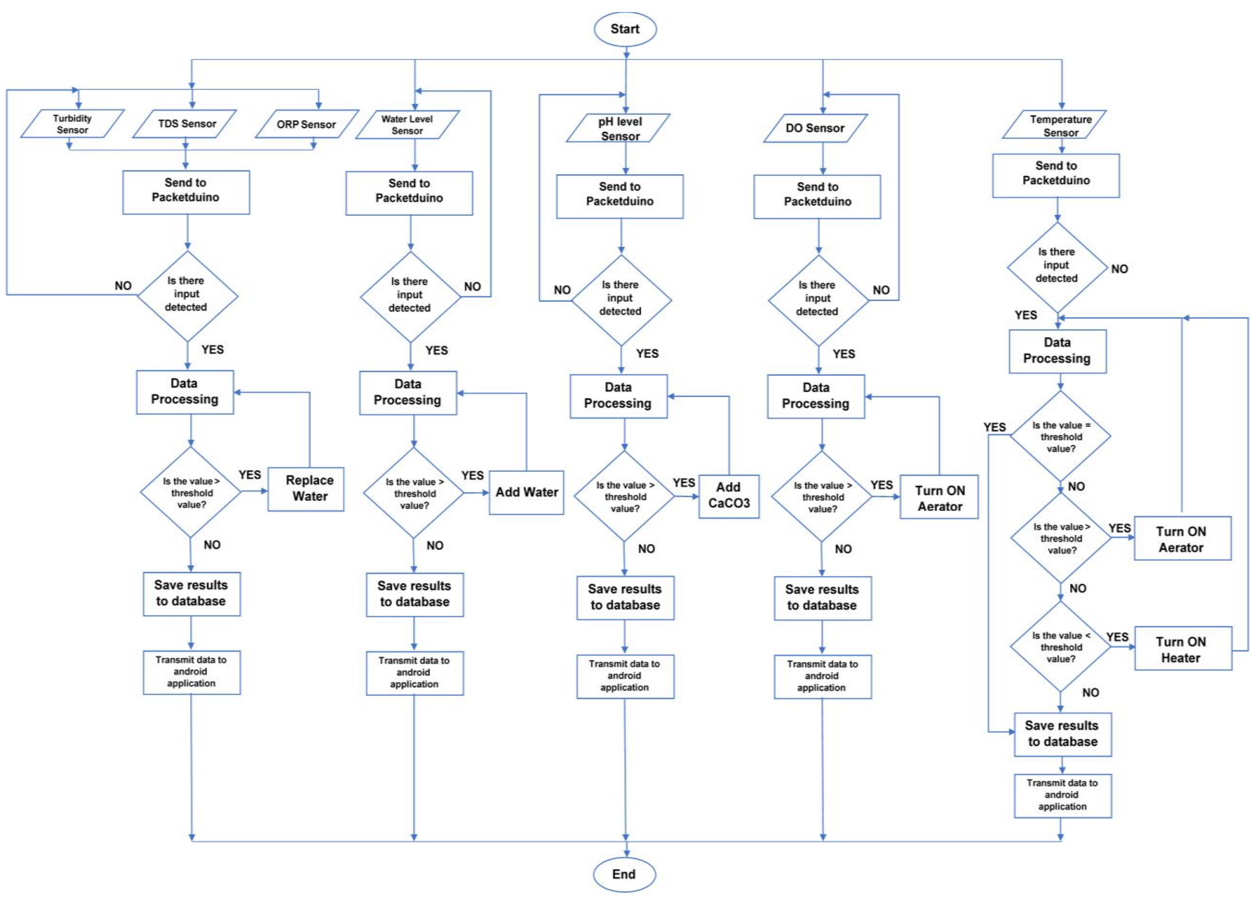

Figure 6. Overall System Flowchart for Data Gathering and Correction

When the gathered data is less than 3 mg/L, the aerator will turn on. The threshold value for the temperature is 24°C to 27°C. When the gathered data is less than 24°C, the heater will turn on and when the temperature is greater than 27°C, the aerator will turn on. If the data gathered by the sensors are within the threshold values their corresponding correctors will remain off, indicating normal readings.

E. *Data Transmission*

In Figure 7, the AQUAlity device gathers data read by the sensors. The Packetduino, a LoRaWAN-enabled microprocessor, will process and transmit the data through connected 868 MHz Antenna to a gateway within 15 km range. Gateways allows the device to securely communicate to the cloud. The LoRaWAN Network Server is responsible for the forwarded data over the Internet. An Application Server (AQUAlity Android App) will manage the fetched data for the end users to view.

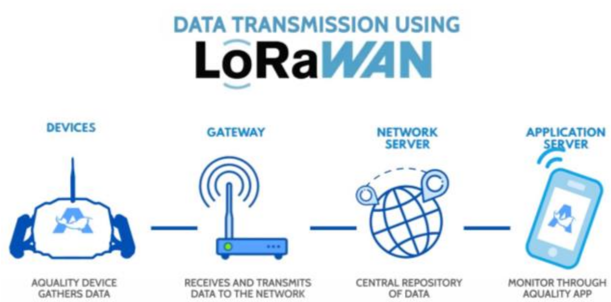

Figure 7. Transmission Process

F. *The AQUAlity Application*

With the use of Android Studio, we developed an Application to monitor the current readings of the water monitoring sensors from the Device. Figure 8 shows the main page of the mobile application where desired species could be chosen and set. It also shows the standard parameter of that species.

Figure 9 shows the parameter status page of the AQUAlity application. This user interface shows the data monitoring of specific water quality parameters including the real-time data visualization and data monitoring through graph representation.

G. *Provision for Battery Supply*

The system could also be operated by a battery. If 12VDC, 12Ah sealed lead-acid battery is used, the system, except the actuators namely, heater, water filter, aerator, motor pump, and 2 peristaltic pumps, can be powered for five days straight considering maintaining 50% depth of discharge of the battery.

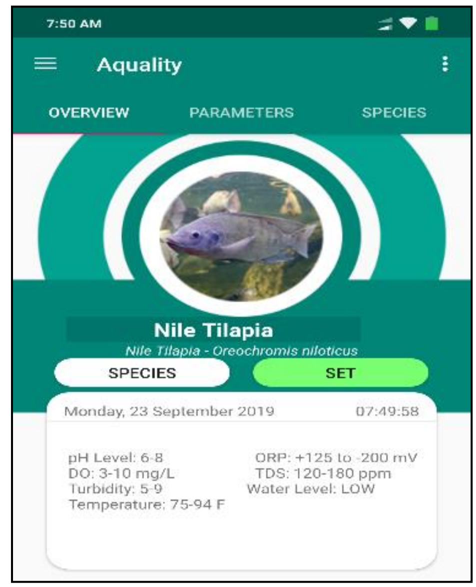

Figure 8. Setting the Fishes to be Cultured as Shown in the App

4. EXPERIMENTAL EVALUATION

Figure 10 shows the device when utilized inside the fish tank. The device was floating in the middle of fish tank floating. Two heaters were placed in the lower left corner and upper right corner of the tank. Water filter in the lower side, air pump in the upper side, and automatic feeder in the right side of the tank were also placed. Meanwhile, Figure 11 shows the device when applied in a fishpond. The device was placed in the middle of the pond guided by the pole. Water filter, air pump, and automatic feeder were all placed on the side of the pond.

To prove that every sensor is calibrated, we compared the readings of the device to a multimeter from BFAR-NIFTC as shown in Figure 12.

Both devices were tested in the same water environment and we were assisted by the BFAR-NIFTC Laboratory Officer-in-Charge to verify that both readings are similar. The multimeter from BFAR-NIFTC was limited in terms of parameters it can measure, it was tricky to setup. According to BFAR-NIFTC, the device itself is costly.

Figure 9. Graphical Interpretation of Data per Water Monitoring Sensor

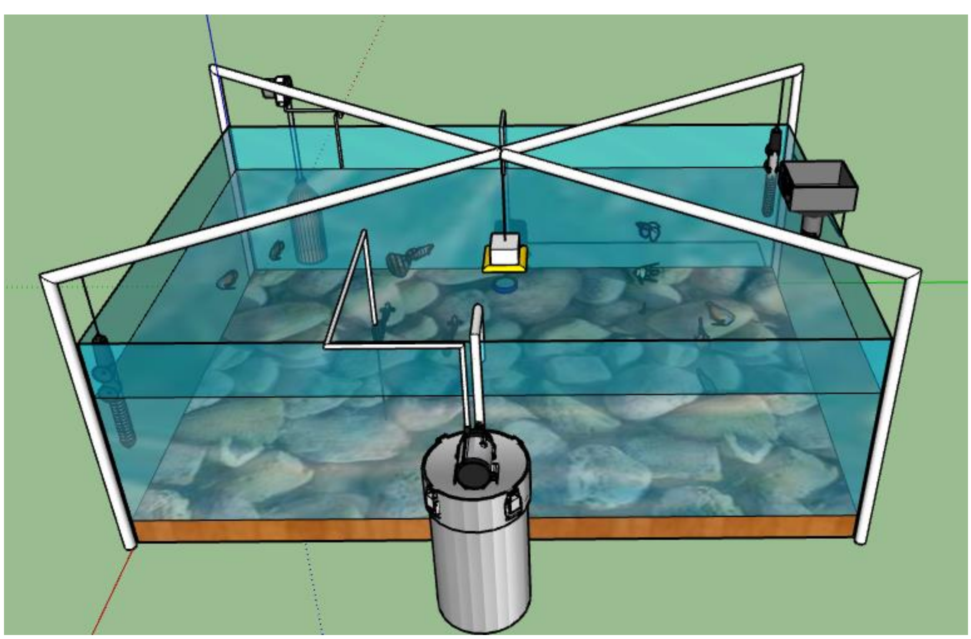

Figure 10. The Device Inside the Fish Tank

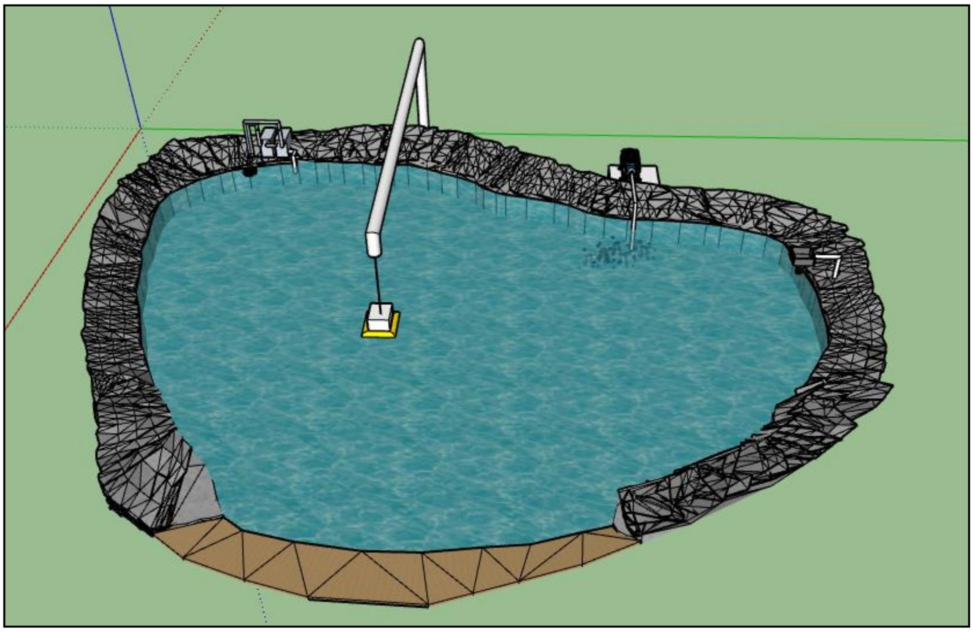

Figure 11. Fish pond set-up

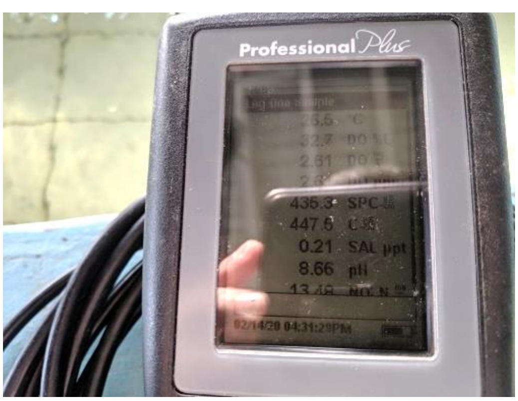

Figure 12. BFAR-NIFTC Multimeter

Table I shows the comparison between the average readings made by the device and the BFAR-NIFTC multimeter. At least 1 minute was required for the readings by our device to be stabilized. The parameter readings for both setups were conducted five trials to ensure the readings were precise and stable. There was no variance between the five readings since it was all the same. There was a low percentage difference between their readings, which was below 2% of the accepted value.

TABLE I. MULTIMETER VS. AQUALITY DEVICE

Water Monitoring Parameter	Multimeter (BFAR-NIFTC)	This work (AQUAlity)	Percent Difference
Dissolved Oxygen	2.61mg/l	2.57mg/l	1.544%
pH level	8.66	8.52	1.63%
Temperature	26.6°C	26.37°C	0.868%

5. CONCLUSION

Our study has shown that both water quality monitoring and correction for aquaculture setup was possible. Compared to a multimeter that can only measure certain parameters for water quality and costly, our device was cheaper compared to buying multimeters with the same parameters as our device, and efficient since everything was automatic. The device hardware with a chassis that floats, and water-repellent; has integrated different water monitoring sensors such as turbidity sensor, dissolve oxygen sensor, pH sensor, water level sensor, total dissolved solids sensor, and oxidation-reduction potential sensor in a single PCB. Our customized PCB allows multiple sensor module to be mounted which made it upgradable. Multiple actuators could also be connected through the relay circuit to program and control its switching. AQUAlity is an important innovation for fish farmers to maintain suitable water quality for their fishes. The integration of up to 10 water monitoring sensors and up to 10 actuators into 2 separate customized PCBs has proven its uniqueness that others do not have.

With the system maintaining the water quality and automated feeding, the growth of fishes was guaranteed without supervision. To make it foolproof, a smartphone was used to monitor the readings from the device. The system also has proven that real-time data acquisition was possible from the device to the smartphones with the help of IoT-LoRaWAN.

For our future works, we would like to improve the size of the device as well as the customized PCBs inside to reduce the cost in 3D and PCB printing. These size adjustments would reduce the weight and increase its stability through the reduction of the center of the gravity in the device. Our team also considers creating a wireless connection between the actuators and the system to lessen wirings connecting to the device, verify users by creating an account unique to each device, and integrate solar panels into the device to make itself sustainable.

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