IoT-Based Real-Time Aquaculture Health Monitoring System

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***Abstract* — Aquaculture fastest growing business worldwide especially in developing countries. Fisheries are marine species and required an oceanic environment where fisheries could grow and live naturally. Off-shore aquaculture businesses need a real-time water quality monitoring system. So, aquafarmers could maintain the required environment for a sustainable and profitable business. This work represents an IoT-based real-time health management system designed for aquaculture and considered the most required health metrics for aquaculture. The proposed system used four primary sensors: water level, temperature, pH, and dissolved oxygen. Sensors connected with microcontroller Arduino Uno R3 and ESP 8266 wi-fi module are used for data transmission to the IoT source ThingSpeak. The designed system could access online through the web interface and phone App for aquafarmers. The sensor data was accurate, and the system worked as designed.**

***Keywords* — Aquaculture, Cloud Technologies, Environment, IoT-based, Microcontroller, Sensors.**

I. Introduction

Over the last few decades, efforts have been made to reduce fish harvesting from the ocean to maintain the ecosystem of the marine environment [1]. As a result, aquaculture is growing fast, particularly in developing countries in the Asia-Pacific region [2]. 18 million population depended on aquaculture in the Asia Pacific region according to the (FAQ) Food and Agriculture Organization of the United Nations [3], and 90% are categorized as small-scale fish farming. Rural areas populations are connected to the fish farm industry mostly, and numbers are increasing in this business that can meet the world food security and sustainable source of income [4] and 65% of population of Pakistan lives in rural areas.

A. Water Quality

Aquaculture requires intense water quality and production care, and in this section, we describe the metrics that need to be monitored. Fish and shrimps are the most widely consumed seafood in around the world. The main parameters should be considered in terms of water quality.

1) Temperature

Water temperature is an essential variable in aquaculture but is uncontrollable in aquacultures and is determined by solar radiation, air temperature, or the temperature of the water passing through the culture unit. Aquaculture must be timed to correspond with water temperature, and measurement accuracy is necessary for efficient operations [5]. Aquatic animals cannot regulate their body temperature and rely on the temperature of their surroundings to survive. There are a few types of species (cold water, warm water, and tropical). Most fisheries require 20 to 25 ºC water temperature for survival. The reproduction of aquatic animals is likely to be hampered by rising water temperature caused by climate change [6].

2) pH

pH is like a temperature-determined value based on a recognized scale. The pH scale span from 1 to 14 is used to determine the degree of acidity in water. The 7 value is neutral, meaning it is neither nor basic; values below 7 are acid, and over 7 are basic. The aquaculture pH level of water must be controlled because fisheries will die in case of high or low levels of pH in water [7]. The aquaculture recommended pH value is 6.5–9.0. and 12 pH is considered chemical or heavy metal solubility and toxic water [8].

3) Dissolved Oxygen

In aquaculture fisheries, low dissolved-oxygen concentration is the primary cause of stress, poor appetite, slow growth, illness, and mortality. The minimum daily dissolved-oxygen content in aquaculture is 6–20 mg/L. During the 24 hours, dissolved oxygen levels can be high. Still, the response of fisheries can be seen to be predominantly influenced by the low level of dissolved oxygen during the night [9].

II. Literature Review

A. Related Work

An IoT-based aquaculture monitoring and control. The IoT method in [10] used technologies in water quality management systems. Raspberry Pi-3 is used instead of Arduino because of its advancement and module connected with turbidity, pH, temperature, and water level sensors. Time series charts display the system quality metrics using the Wi-Fi module. Aqua monitoring system using AWS [11] is another technology available for data storing and analysis. The ESP32 microcontroller and DHT11 were used to monitor the temperature, water level sensor, and fish feeder for the fish farm. Data can be accessed anywhere using the Amazon web services dashboard MQTT protocol chosen for transmitting the data to the AWS cloud from the microcontroller. Another work found in [12] wireless sensor network model for shrimp culture monitoring using open source IoT. Arduino microcontroller used with pH, dissolved oxygen, and temperature sensors. An open source IoT is created using

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ThingSpeak channels. The system is not included a Phone app and web interface, which is inefficient for displaying the data.

B. Problem Statement

It can be observed in the literature review that aquaculture is one of the most growing industries in developing countries. The practice of rearing marine fisheries in an artificial environment such as ponds and tanks is known as aquaculture. While production of these fisheries in artificially designed environments, many factors come into consideration. Financial development and food production are critical in this activity and facing enormous global challenges. The most significant are viral, bacterial, and fungal diseases. All of them were discovered as a result of water quality.

Water quality changes can stress the fisheries and threaten their survival. To determine water quality parameters, most aquacultures rely on manual methods. Manual testing takes time and produces inaccurate results because of the parameters and, on the other hand, insufficient facilities close to their aquaculture. Parameters of water measurement change regularly and are inconsistent.

III. Proposed Model and Design

A. System Design

This System design consists of two categories. The first is the hardware setup, and the second is software implementation. First, assembling and calibrating sensors and connection with microcontroller Arduino UNO R3. The second part is programing the Arduino and establishing a connection with Wi-Fi for sending data to the server.

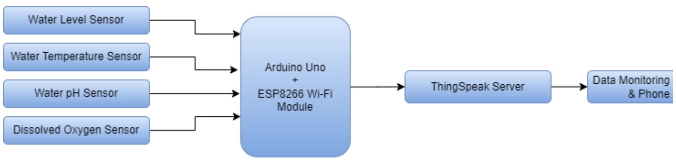

Fig. 1. Block diagram of the proposed System.

Fig. 1 describes the block diagram of the proposed system. The system depends on four primary sensors and is connected to the microcontroller. Wi-Fi module ESP8266 used with Arduino UNO R3 for communication with server ThingSpeak. The Fish farm is off-grid and operates through a 100% solar-powered PV system. So, the health monitoring system can also be accessed through a website and phone App.

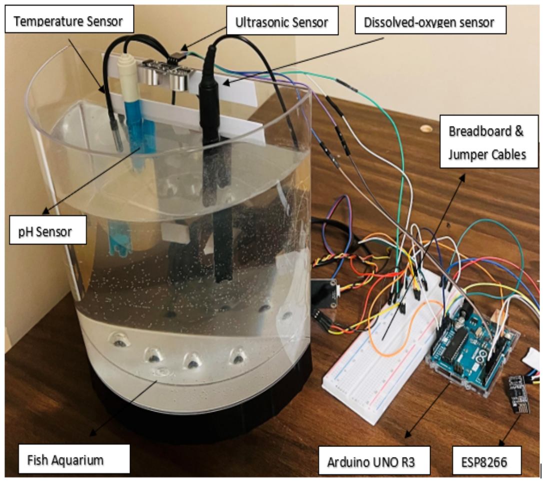

Fig. 2. Proposed Health Monitoring System.

The hardware assembled proposed system is illustrated in Fig. 2. The micro-controller Arduino Uno R3 is used with the ESP6288 Wi-Fi module. The system is designed for the four most crucial water metrics measurements, and these values are taken by using water level, temperature, water pH, and dissolved oxygen sensors. The fish aquarium is used for system testing. An aquarium with tap water and sensors hung into it to get data from the sensors. Sensors are calibrated before installation and precisely checked using standard techniques such as pH sensor in buffer solution, dipping the dissolved oxygen sensor in zero dissolved solution, temperature sensor, and ultrasonic sensor reading using physical scale.

1) Arduino Uno R3

Fig. 3 shows Arduino UNO is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins, six analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, ICSP header, and a reset button. Simply can connect to the computer through a USB cable. This microcontroller is readily available at a low cost [13].

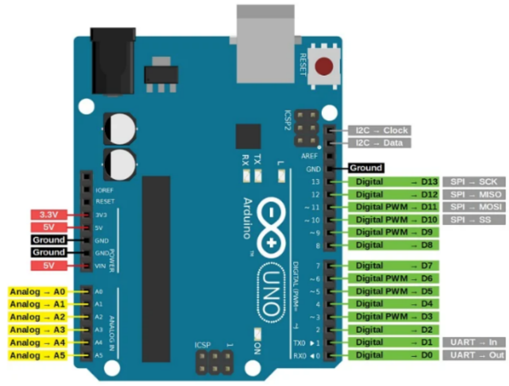

Fig. 3. Arduino Uno R3.

2) Ultrasonic Sensor

An ultrasonic sensor is an electronic device used for the measurement of the distance of any object by ultrasonic waves and converts the reflected sound into an electric signal [14]. HC-SR04 model is used for automation and control of the pumping system. The sensor comprises a receiver and transmitter side that process the signals as input and output. The sensor is shown in Fig. 4.

Fig. 4. Ultrasonic Sensor.

3) Temperature Sensor

The waterproof temperature sensor DS18B20 measures the temperature in Fig. 5. This sensor is capable of any liquid in wet conditions for measuring temperatures ranging from -55 ºC to 125 ºC and can be powered by a 3.0 V to 5.5 V power supply. The sensor cable is coated with PVC. The best is to keep using under 100 ºC. The dallastemperature.h downloaded through the IDE library, which is required to use this sensor with Arduino Uno R3. Sensor specification is described in Table I, and pin connections in Table II.

TABLE I: SPECIFICATIONS OF DS18DS20

voltage	3~5 V.
Measuring range	-55~+125 °C.
Accuracy	±0.5 °C.
Conversion time	750 m at 12-bit

TABLE II: TEMPERATURE SENSOR AND ARDUINO PIN CONNECTIONS

Pin Connections	
Temperature sensor Pins	Arduino Pins
Red wire	5V.
Black wire	GND
Yellow wire	12.

Fig. 5. Temperature Sensor.

4) pH sensor

Water pH level is the essential part of this designed system. Fig. 6 DFRobot SEN0101 sensor used, which is known for accuracy in the market and readily available. Results found this sensor is ideal for water quality testing and aquaculture. This sensor is an analog pH sensor designed for Arduino and Raspberry Pi. The sensor works on the electrical potential principle produced. pH value determines based on the measurement electrode and the sensor' reference electrode. Obtained value first received in millivolts, then converted it to the pH using the formula in the code during programming. Sensor specification is described in Table III and pin connections in Table IV.

TABLE III: SPECIFICATIONS OF SEN0101

voltage	5 V.
Measuring range	0~14 pH.
Operating Range	0~60 °C.
Accuracy	0.1 pH
Response time	Less than 1 min.

TABLE IV: PH SENSOR AND ARDUINO PIN CONNECTIONS

Pin Connections	
pH sensor Module Pins	Arduino Pins
Signal/ A	AO
-	GND
+	5V

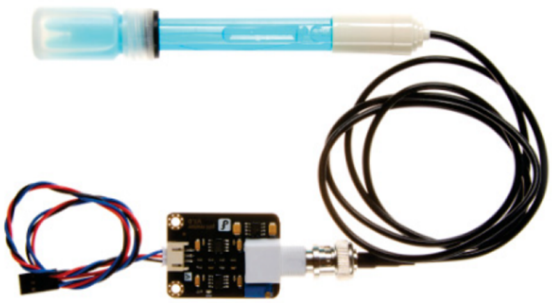

Fig. 6. pH sensor.

5) Dissolved-Oxygen Sensor

Another critical parameter is the dissolved-oxygen level in the aquaculture pond for fisheries life. Fisheries could die in low levels of oxygen in the water. For this reason, maintaining oxygen level in the water and monitoring oxygen value is most important. Fig. 7 SEN0237 dissolved-oxygen sensor found for aquaculture and environment monitoring is compatible with Arduino micro-controller. Sensor specification is described in table 5 and pin connections in Table VI.

TABLE V: SPECIFICATIONS OF SEN0237

Input voltage	3.3-5 V.
Measuring range	0~20 mg/L
Operating Range	0~40 °C.
Pressure	0~50 PSI
Response time	90 seconds

TABLE VI: DISSOLVED OXYGEN SENSOR AND ARDUINO PIN CONNECTIONS

Pin Connections	
pH sensor Module Pins	Arduino Pins
Signal/ A	A2
-	GND
+	5V

Fig. 7. Dissolved oxygen sensor.

B. Sensor Calibration

Sensor calibration must be imported using standard techniques to obtain accurate data before connecting with Arduino. Without calibration using, sensors may be resulting inaccurate measurements. To avoid inaccuracy in measurement values, calibration must be completed before use. The below subsections details describe the calibration of the proposed system sensors.

1) pH Sensor Calibration

Simple and quiet calibration needs for pH sensors compared to other sensors. Buffer solution provided in the packaging used for dip sensor probe, measuring the values, and comparing. Verify the values of the sensor on the serial monitor with buffer solution values.

2) Dissolved Oxygen Sensor Calibration

A similar method was used to calibrate the dissolved oxygen level sensor. Mainly Sodium Hydroxide (NaOH) solution is required to calibrate the sensor. NaOH solution was prepared and obtained from the chemical laboratory of the university under the safety measures because NaOH is hazard marked chemical and required proper handling with care. NaOH could affect the skin with irritation, burning sensation, and not allowed to smell. 0.5M NaOH has required one-time calibration for the sensor membrane. Single point calibration is recommended and the most common way to use it. First, open the membrane cap, fill it with 0.5M NaOH, close its lid and leave it in the open air for a few seconds, then dip it into sample water for 90 seconds at a temperature of 23 ºC. This time is to write down the voltage value of the sensor by using a serial monitor display and add this value into the code under the calibration command code. The chemical solution can see in Fig. 8.

Fig. 8. NaOH Flakes and Solution.

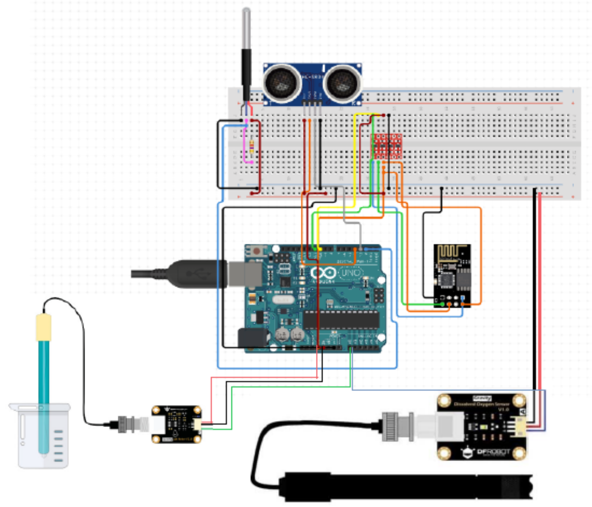

Fig. 9. Diagram of the circuit.

Fig. 9 is the connection diagram of the designed system. Arduino Uno connections with ESP8266, ultrasonic water level sensor, temperature sensor, water pH sensor, and dissolved oxygen sensors are shown in the figure above.

C. Software Implementation

After hardware setup, the second part is software implementation required for the system configurations. On the other hand, suppose the hardware is the backbone of the system. In that case, software implementation is the skin of the system. The software communicates between components, obtains the results from the hardware, and displays the result with time series on the web server and over the phone. Three sub-sections define the software part implications below:

i. IDE for Arduino Programming.
ii. Writing Data to the Cloud server.
iii. Reading Data on website and Phone App.
iv. IDE for Arduino Programming.

IDE Stands for (Interpreter Developed Environment) designed by Arduino.cc. IDE is available open-source online and compatible with all Arduino modules microcontrollers, ESP32, MKR1000, Arduino Uno, Arduino Mega, and Arduino Nano. IDE could use online and install in all windows operating systems. IDE provides two main parts an editor and a compiler. The compiler is used for compiling and uploading code to the Arduino module by using codes in the editor. C and C++ languages can use to write the code in IDE [15].

After installing the IDE in the Operating system, Editor prompts up while opening the IDE and using Tools from the tab bar to install the required libraries according to the microcontroller module and sensors. After installing the required libraries, the editor is ready to write the code.

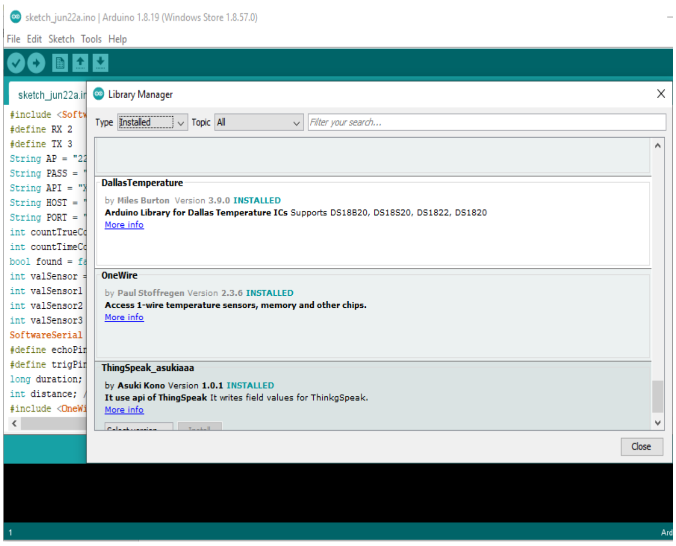

Fig. 10. IDE Editor and Library Manager.

Arduino Uno microcontroller was chosen for the proposed system. Therefore, Arduino Uno was installed to connect the microcontroller from the library manager, and also installed ESP8266 Library for data transmission through the wi-fi. We also required sensor libraries for the Ultrasonic sensor, Temperature sensor, pH sensor, and dissolved oxygen sensor. ThingSpeak server is used for data transmission and displays wirelessly so that the ThingSpeak library can be seen in Fig. 10. After installing the required libraries, start writing and compiling the code. If any error detects in the code button black console displays the errors. Setting up the correct code after error removal, upload the code to the microcontroller, and can see the values of the system on the serial port by clicking up the Toolbar. The system flow chart below can be seen in Fig. 11.

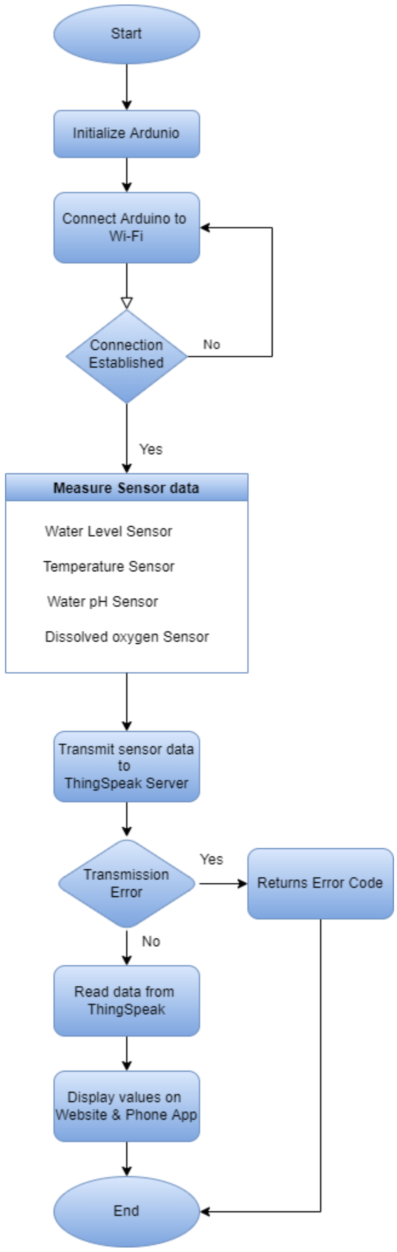

Fig. 11. Flow Chart of the proposed system represents the functions.

1) Writing Data to the Cloud server

Cloud technologies are renowned these days and transformed the world by providing data storage and IoT services. Many cloud sources are available online Azure, AWS, ThingSpeak, and many more. ThingSpeak was chosen for this proposed system because of its free and open source IoT analytics platform and data storage. On the other hand, other sources are more expensive. The ThingSpeak library is available on IDE, which makes the user very easy to configure. ThingSpeak offers 8 channel fields to access for reading the data. It means 8 sensors could be set up one-time using ThingSpeak.

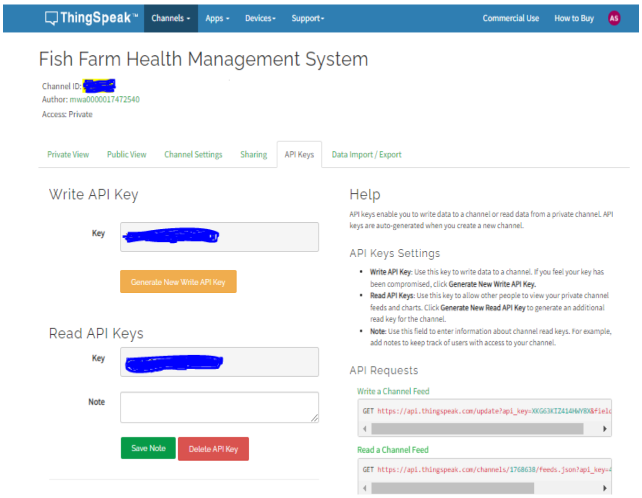

Fig. 12. ThinkSpeak Channel ID and API keys.

After writing the correct codes, Microcontroller connected to the Wi-Fi through ESP8266. ThingSpeak Channel was created on the name of our proposed system in Fig. 12. Then unique channel ID and API keys are generated for the system. These API keys are used in the code to transmit the data from Arduino to the ThingSpeak channel. Using ThingSpeak Channel ID, API keys, and local Wi-Fi credentials, writing the final code and uploaded it to the Arduino Uno microcontroller. Write API key used for data transmission and read API key displays the data on the dashboard into the designated field channel of every separate sensor.

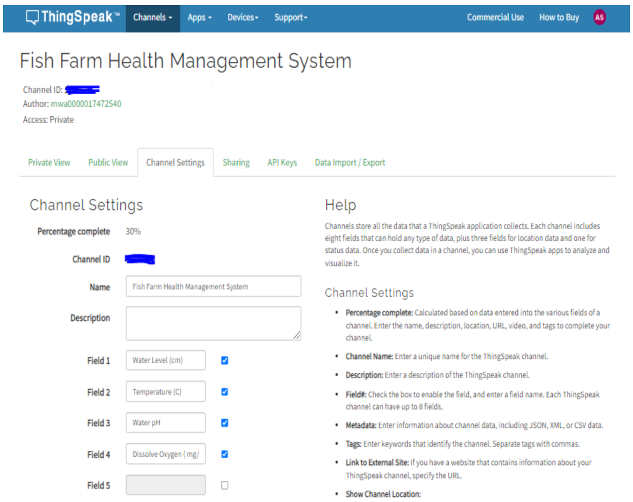

Fig. 13. Channel fields set up.

After uploading the code using the API key into the Arduino, we set up the channel fields in the ThingSpeak and created 4 fields named with the water level, water temperature, water pH, and dissolved oxygen level. To display the data with time series added widgets for sensors and data visualizations. Fig. 13 shows the field channel settings, and ThinkSpeak also provides MATLAB analysis and visualizations.

2) Reading Data on Website and Phone App

Data was successfully transmitted from Arduino to ThingSpeak, and all sensor data was displayed on the ThingSpeak Channel on their website. ThingSpeak offers online channel access in private mode, and data visualization by time series can be seen.

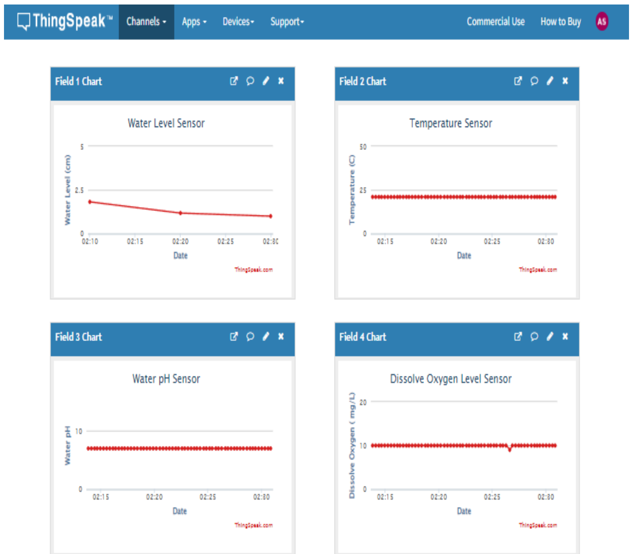

Fig. 14. Data display dashboard on ThingSpeak.

Data display can be seen in Fig. 14 on the dashboard of the ThingSpeak channel. 4 Fields established for four sensors, and data transmission was accurately observed in all four fields. Data displayed with time series and measurement unit mentioned on the y-axis. Field 1 is for water level, field 2 is for water temperature, field 3 is for water pH, and field 4 is for dissolved oxygen.

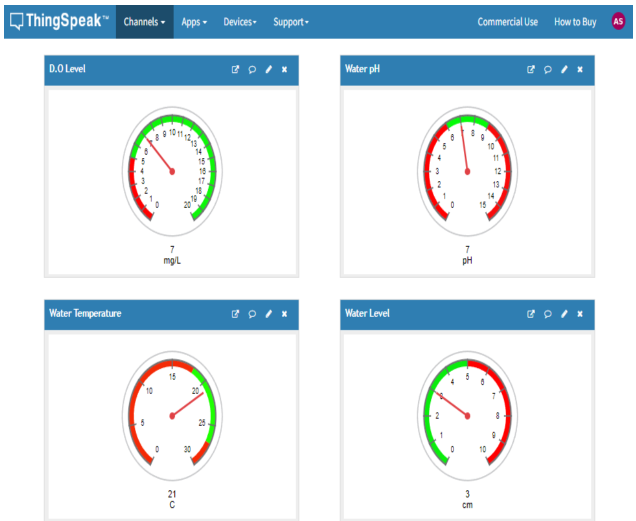

Fig. 15. Dashboard widget Display.

Another display can be seen in the Fig. 15 dashboard widget. These gauges are set up according to each sensor type. Each gauge is designed to be a sensor measurement unit and value range. Gauges are colored red and green, which indicates the value ranges. The green color range indicates the average level for health aspects; on the other hand, red colored values indicated the threating or unacceptable values per fish farm required health standard. We use simple tape water for designed system testing, and all values from the sensors are under the green range of the gauges, which means water quality is acceptable. Dissolved oxygen level observed at 7 mg/L, which is good as required between 6–20 mg/L, water pH level indicated 7pH which is the neutral value of pH level, water temperature observed 21 Celsius fish farm required between 20–27 ° C. The water level is observed at 3 cm. If the water level goes down from 5 cm, then consider the low water level in the aquarium as per our physical system. Hence, all values from the sensor are correct.

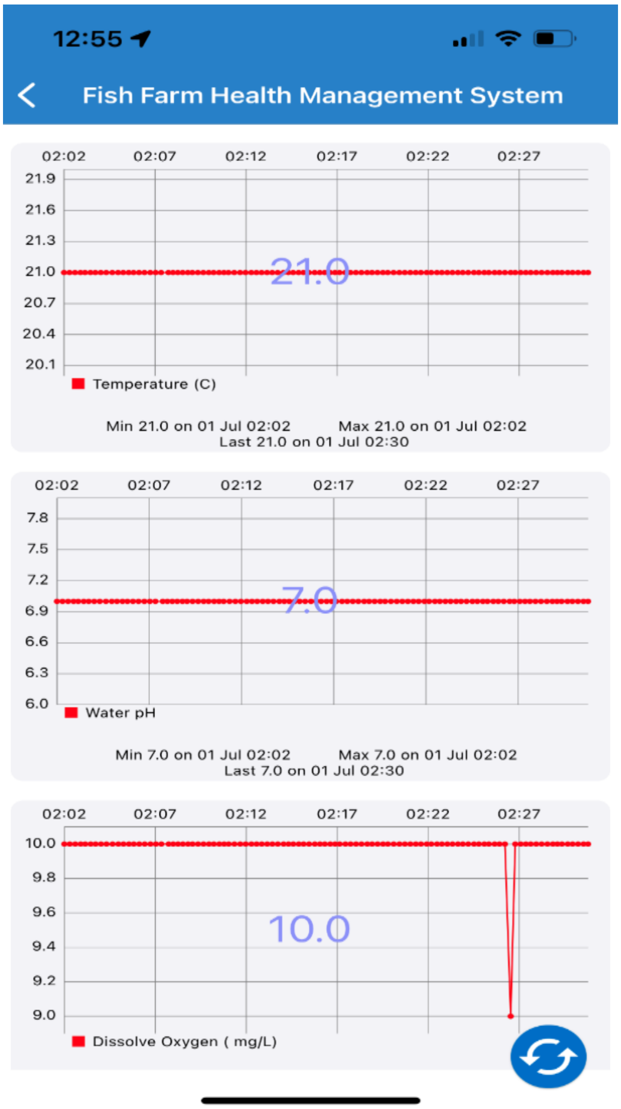

Fig. 16. Phone App Dashboard display.

The proposed system could successfully access the Phone App provided using the API key and channel ID by ThingSpeak. Aquafarmer can access the fish farm health monitoring system remotely using their phone. This IoT-based system can increase the production and profit of the fish farm because of the real-time aquaculture health monitoring system. Easily could maintain standard health parameters in Fish farm at low cost. The phone App display can be seen in Fig. 16.

IV. Conclusion

The designed proposed system concluded that real-time fish farm health monitoring is suitable for fish farms and can be used in aquaculture, such as hydroponics, riverbed, tank fish farms, etc. The proposed system continuously monitored the health measure of the fish farm and displayed them on the phone and website in real-time. The system must be evaluated on full-scale industrial trials before being employed on a large scale. Low cost, easy to use, and efficient system for developing countries

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References

[1] Leung TL, Bates AE. More rapid and severe disease outbreaks for aquaculture at the tropics: implications for food security. *Journal of applied ecology*, 2013; 50(1): 215–222.

[2] Belton B, Karim M, Thilsted S, Collis W, Phillips M, *et al*. Review of aquaculture and fish consumption in bangladesh. Studies and Reviews. *The WorldFish Center*. November 2011;(53).

[3] Dept AO. The state of world fisheries and aquaculture, Food and Agriculture Organization of the United Nations. *Fisheries*, 2014.

[4] B´en´e C, Macfadyen G, Allison EH. Increasing the contribution of small-scale fisheries to poverty alleviation and food security. *Food & Agriculture Org*. 2007;(481).

[5] Blogger. *Understanding water quality for aquaculture | WorldWide aquaculture*. [Online]. 2015 March 5. Available: http://worldwideaquaculture.com/understanding-water-quality-for-aquaculture/

[6] Global Seafood Alliance. *Water temperature in aquaculture - responsible seafood advocate*. [Online]. 2018 Nov 26. Available: https://www.globalseafood.org/advocate/water-temperature-in-aquaculture/

[7] Fondriest Environmental Inc. *pH of Water. Fundamentals of Environmental Measurements*. [Online]. 19 Nov. 2013. Available: https://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/>.

[8] Swann L. A Basic Overview of Aquaculture: History-Water Quality Types of Aquaculture-Production Methods. *Iowa State University*, 1992.

[9] Global Seafood Alliance. *Dissolved oxygen dynamics - responsible seafood advocate*. [Online]. 2018 Aug 20. Available: https://www.globalseafood.org/advocate/dissolved-oxygen-dynamics/

[10] Preetham K, Mallikarjun B, Umesha K, Mahesh F, Neethan S. Aquaculture monitoring and control system: An iot based approach. *International Journal of Advance Research*: *Ideas and Innovations in Technology*. 2019;5(2).

[11] Kodali RK, Sabu AC. Aqua monitoring system using aws. *International Conference on Computer Communication and Informatics (ICCCI).IEEE*: 2022: 1–5.

[12] Goud CS, Das S, Kumar R, Mahamuni CV, Khedkar S. Wireless sensor network (wsn) model for shrimp culture monitoring using open source iot. *Second International Conference on Inventive Research in Computing Applications (ICIRCA). IEEE:* 2020:764–767.

[13] Arduino Documentation. *UNO R3*. [Online] 2022 April 14. Accessed https://docs.arduino.cc/hardware/uno-rev3.

[14] Parallax. *PING))) Ultrasonic Distance Sensor*. [Online] 2022 Aug 12. Retrieved from https://www.parallax.com/product/ping-ultrasonic-distance-sensor/.

[15] Fezari M, Al Dahoud A. Integrated development environment “ide” for Arduino. *WSN applications*. 2018: 1–12