Advances in Research

Volume 24, Issue 5, Page 100-123, 2023; Article no.AIR.101041
ISSN: 2348-0394, NLM ID: 101666096

Smart Aquaponics System for *Oreochromis niloticus* Production

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AIR/2023/v24i5963

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/101041

Original Research Article

Received: 09/04/2023
Accepted: 13/06/2023
Published: 26/06/2023

ABSTRACT

Surigao City, found in the Northeastern part of Mindanao and facing the Pacific Ocean, boasts an abundance of fish; however, their prices are still high. This situation is due to the limited supply of freshwater fish, specifically Tilapia (*Oreochromis niloticus*), which is attributed to fishermen continuing to employ traditional fishpond methods. Considering this, the aim of this research is to design and develop a smart aquaponics system that incorporates recirculating aquaponics system (RAS) technology. The aim is to enhance the supply of Tilapia in the market. To achieve this, a developmental research design has been employed to create an efficient aquaponics system. The project incorporates two microcontrollers and multiple sensors to check essential parameters such as pH level, total dissolved solids, temperature, and water level. The study's results show a remarkable 6% fish growth, consistent operation of the system's circuit functions and water circulation, real-time data logging eased by the application software, and a power consumption of 193 watts. To examine the data acquired from the study, the researchers employed statistical methods such as mean, standard deviation, and frequency count. The tables and figures contain information on the system's hardware and software requirements, Tilapia growth characteristics,

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and a data overview of all sensor readings. The findings reveal that the smart aquaponics system could produce considerable growth of Tilapia within the tank while preserving fish development factors such as pH, salinity, total dissolved solids, temperature, and tank water level. The system likewise consumes less electricity and was rated "very acceptable" based on quantitative overall findings. These findings lead to the conclusion that Tilapia can effectively mass-produced using this aquaponics system. However, further research is necessary to prove a correlation between Tilapia grown in the smart aquaponics system and those raised through traditional fishpond methods.

Keywords: Control; aquaponics; tilapia (Oreochromis niloticus); smart; sensor.

1. INTRODUCTION

Production is a developmental idea that combines a bio-integrated agricultural production using internet of things-based technological method of producing *Oreochromis niloticus* [1]. The project has three hardware systems namely water level control, smart feeding system, and water quality monitoring and control, each has a designated function [2]. All the systems are wirelessly connected to the internet via the Raspberry Pi and all the data gathered are analyzed and stored in the cloud and eventually decide to actuate the necessary relays [3]. The systems were all smart and wirelessly connected, providing real-time monitoring and control.

The project was developed intending for the use of the small-scale commercial farming in the locals of the Surigao Del Norte [4]. Traditionally, implementing aquaponics uses extensive human labor, absence accountability or responsibility to the environment, use of low-tech tools and is inefficient [5]. Meanwhile, the project’s intent with the use of new technology such as IoT, smart-sensor, and instrumentation control to address the common struggles of the farmers, saving so much labor cost, promoting safety, accuracy, and efficiency [6]. The Project design is a low-cost, easy-to-use, and sophisticated equipment to be used in farming.

High quality tilapia has a ready local market and with great potential in foreign market [7]. It provides a readily available supply of table fish for both rural and urban families [8]. It is the source of cheap protein for Filipinos. Therefore, in line with the problem, we aim to create a smart aquaponics system that caters to the production of the Tilapia [9]. With the help of the IoT technology, smart sensor and process instrumentation, the project was developed to create a facility that cater the production of tilapia ensuring the safety and its high quality, in addition to that, the system would be easily adapt the by small-scale commercial level farmer, coping the great market demand [10].

The goal of this research is to increase Tilapia (*Oreochromis niloticus*) production by incorporating smart technology and farming, which would enable for a thorough food production system that is still viable, generates slight waste that resembles nature's circular approach, requires daily tasks such as harvesting and planting that are labor-saving, and allows for greater control. Aquaponics can be used to integrate livelihood strategies for small-scale and poor households to guarantee food and small incomes [11]. Moreover, compared to conventional agriculture, this sort of farming produces significantly more food with significantly less resources, space, and manpower [12].

In addition, this will be established and support proper production of Tilapia and provide automation that can be accessed via the internet. This technology with the state-of-the-art facility can provide productivity and reduce human labor, guaranteeing profit and efficient operation management. In this study, the most beneficial are the rural and urban families by providing them with a good product of Tilapia fish for one of their food sources.

2. RELATED LITERATURE

In this section review some existing literature concerning Smart Aquaponics system.

Getting fish and plant water appears to be challenging. Diverse, land-and water-saving veggies may reduce production [13]. Aquaponics acidity, water level, and water temperature. A promising remedy to the current food and environmental issues confronting the globe is aquaponics farming [14]. Because it uses less water, less pesticides, and fertilizer, this approach promises to be sustainable and kind to the environment [15]. It combines aquaculture with hydroponics. Aquaponics needs clean water. -Measuring oxygen, temperature, and acidity. IoT, embedded electronics, and cloud computing ease aquaponics water quality monitoring. The system uses http, a standard protocol. HTTP and IoT enabled IoT aquaponics (IoT) [16].

The Internet of Things advances technology. Internet usage is common. IoT-based home security systems grew crucial as technology developed. Due to expensive microcontrollers and microprocessors, the current home security system was too expensive [17]. A home security server and software are required online. Infrared sensors are passive or active. The sensors detect trespassers [18].

Bluetooth feeds an LCD app and out-of-range parameters trigger an SMS. A microcontroller-based aquaculture app will be created. Include or remove rated liquid in two high-speed dc pumps [19]. User-friendly software assesses water quality and other features. Small-pond farmers can't hire staff to manage water level, temperature, and fish/shrimp feeding. Cloud-integrated applications can monitor pH, water temperature, humidity, and pH. A study describes a prawn/fishpond management system [20]. The system detects, displays, and estimates online stress using PDSS. Networking ponds enable centralized control and presentation of growth and development of fish in the event of an unexpected increase in population growth [21]. Smart Aquaculture automates feeding, cage monitoring, feeding schedule, and volume to save labor. Submerged fish cages minimize labor and feed costs in open-water aquaculture. We fitted a feeding mechanism and a smartphone to remotely control it for automated feeding.

An idea is to alert pond owners through text message when incursions occur [22]. Water is automatically replaced whenever it lowers thanks to Smart Fishpond Management. Police are alerted to occurrences by sensors [23]. Lime is subsequently added as necessary after a pH check. A motor then starts pumping water up or down in response to the temperature of the water. Intelligent was developed to address food security and water scarcity while automating aquaponics farming techniques [24]. To check the device's dependability, it built a prototype. Continuous monitoring of the complex system is done by a separate control system. The soil is preserved, water and nutrients are used effectively, and fertilization is applied responsibly [25].

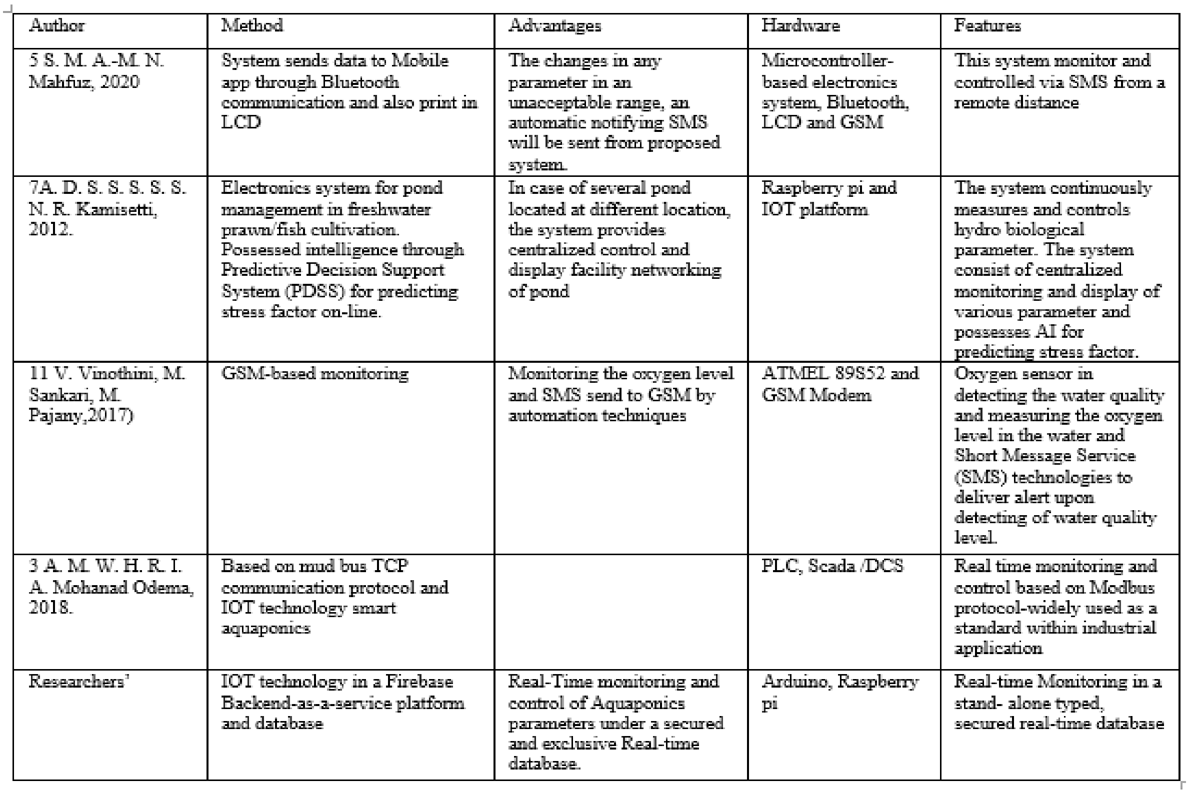
Temperature, pH, and dissolved oxygen are all necessary for prawn survival. In prawn farming, manual monitoring causes problems; as a result, a remote intelligent system is advised. An oxygen sensor is used by the system to monitor the oxygen level and water quality, and SMS alerts the owner [26]. GSM has SMS capability (GSM). Mifare tags and a database are used to establish an RFID system for a deer farm. The app displays the gender, species, and year of birth of RFID-tagged deer.

Water quality is evaluated via sensors. Sensor data is read by the Arduino controller. WI-FI enables online viewing of sensor data [27]. This study suggests a low-cost IOT (internet of things) water quality monitoring solution for usage in homes and enterprises all around the world. Water quality is evaluated via sensors. Sensor data is read by the Arduino controller. WI-FI enables online viewing of sensor data. This study suggests a low-cost IOT (internet of things) water quality monitoring solution for usage in homes and enterprises all around the world [28]. An IOT-based water quality monitoring system is presented in this study. A microcontroller transmits sensor data to the Raspberry Pi through Zigbee, measuring pH, turbidity, conductivity, dissolved oxygen, and temperature. Sensor data is easily accessible because to cloud computing [29].

2.1 Conceptual Framework

The waterfall model, represented in the picture below, is used by academics because of its linear and sequential structure. This study will continue to be conducted in cycles when key tasks are completed. The first step will be material acquisition, in which the researchers will obtain all necessary materials, followed by assembly, in which all materials will be assembled. The programming aspect will be substantial work and a crucial part in the third stage of the research endeavor. If a mistake occurs when programming, the study might be returned to the assembly step. Following the researchers' programming of the system, the fourth step will be data collection, followed by the fifth stage of data finalization. The sixth step is the test and evaluation phase, which involves the researchers testing and evaluating the study project in preparation for a final evaluation. Data collected from the final assessment is the seventh and last step. During this step, the researcher gathers input from stakeholders.

Table 1. Performance comparison of the state of the literature



Author	Method	Advantages	Hardware	Features
5 S. M. A.-M. N. Mahfuz, 2020	System sends data to Mobile app through Bluetooth communication and also print in LCD	The changes in any parameter in an unacceptable range, an automatic notifying SMS will be sent from proposed system.	Microcontroller-based electronics system, Bluetooth, LCD and GSM	This system monitor and controlled via SMS from a remote distance
7A. D. S. S. S. S. S. N. R. Kamisetti, 2012.	Electronics system for pond management in freshwater prawn/fish cultivation. Possessed intelligence through Predictive Decision Support System (PDSS) for predicting stress factor on-line.	In case of several pond located at different location, the system provides centralized control and display facility networking of pond	Raspberry pi and IOT platform	The system continuously measures and controls hydro biological parameter. The system consist of centralized monitoring and display of various parameter and possesses AI for predicting stress factor.
11 V. Vinothini, M. Sankari, M. Pajany,2017)	GSM-based monitoring	Monitoring the oxygen level and SMS send to GSM by automation techniques	ATMEL 89S52 and GSM Modem	Oxygen sensor in detecting the water quality and measuring the oxygen level in the water and Short Message Service (SMS) technologies to deliver alert upon detecting of water quality level.
3 A. M. W. H. R. I. A. Mohanad Odema, 2018.	Based on mud bus TCP communication protocol and IOT technology smart aquaponics		PLC, Scada /DCS	Real time monitoring and control based on Modbus protocol-widely used as a standard within industrial application
Researchers'	IOT technology in a Firebase Backend-as-a-service platform and database	Real-Time monitoring and control of Aquaponics parameters under a secured and exclusive Real-time database.	Arduino, Raspberry pi	Real-time Monitoring in a stand- alone typed, secured real-time database

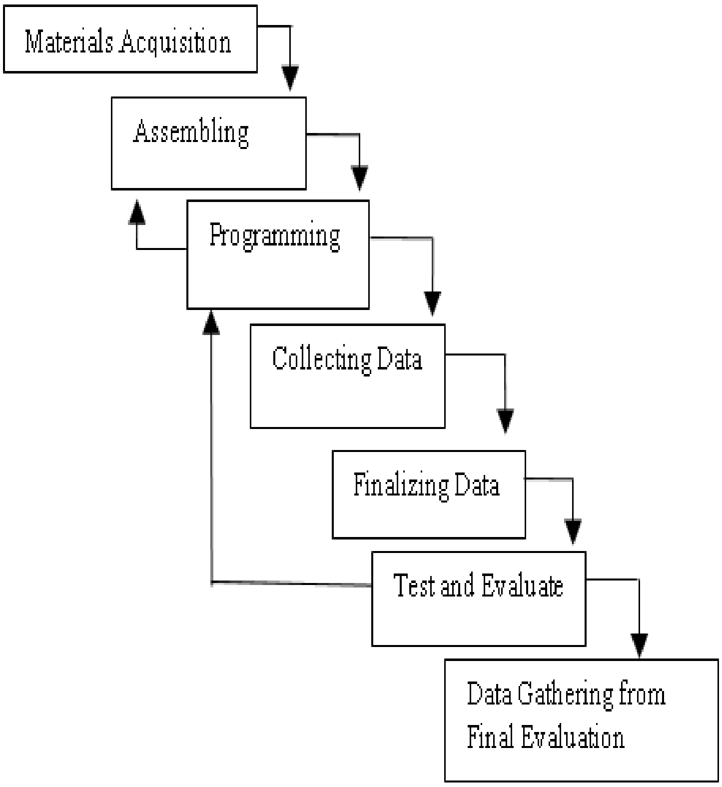


Fig. 1. Waterfall model diagram of the study

As shown in Fig. 1. The flow diagram begins with the analysis phase, during which the researchers ascertain the complaints and requests of the stakeholders and assess the viability of producing the materials and equipment required to visualize the research project, such as the Arduino Uno, Raspberry Pi, Actuator, and Sensors, before moving on to the Website phase. The process stage, where planning, development, system design, system analysis, testing, and implementation take place, is the next step the researchers take after visualizing. This stage is essential since it could entail intricate calculations and trial and error. The product from the Smart Aquaponics System for *Oreochromis niloticus* Production is expected to measure the parameters and deliver them wirelessly through the owner's cell phone.

Analysis Phase: The first stage of the project entails a thorough and detailed description of how the hardware and software that will be developed will behave. The first step is to compile stakeholder requests and complaints, in this case from the BFAR staff, fish dealer, and fishermen. The project's stakeholders then carry out a feasibility assessment and pre-survey. The project team then compiles and combines each person's plan for cost, scope, duration, quality, communication, and risk. Pre-Survey and status evaluation, followed by customer-facing Target need.

Design Phase: It is the planning and issue-solving process for a software solution. First, the demand from the target stakeholder (Design criteria: Coverage, capacity, and quality). The detail design was then made by a designer on the project team (system diagram, power budget, coverage plan, Block diagram, Flow Chart arrangement). Finally, submit a proposal after discussing the installation issue (problems with the system diagram and stakeholder solutions) (installation, Drawing, Materials list).

Implementation Phase: This refers to the transformation of the demand and design specification into a tangible, operational IOT device during this phase. First, the project's implementation materials are organized (permit and contract). Then, a schedule is formed, materials are ordered, tolls are ordered, instructions are provided to the staff, and so on. Potential suppliers or subcontractors are then called in. This stage entails creating the project's actual output.

Testing Phase: The process of ensuring that the IOT solution complies with the original requirement and specification and serves the intended purpose is known as verification and validation, or IT. Test the usability, dependability, security, and performance first. Gray box testing should be used with IOT testing since it enables the creation of efficient test cases. To provide the scalability, adaptability, connection, and security required for IOT, Real Time Operating System is essential. Site and parameter audit comes last.

Evaluation Phase: It is the process of changing a software solution after delivery and deployment to improve performance and quality. First, everything is set up during this phase that is required to bring the project to a successful conclusion, including user manuals that provide instruction and training. The team is then dismantled, and the project's direction is changed.

2.2 Objectives

The general objective of this study is to design and develop a smart aquaponics system based on RAS technology for Tilapia production, aiming to enhance the tilapia supply in the market.

The specific objectives of this study are as follows:

1. To determine the optimal parameters for fish growth, including:
   1.1 Water level/depth
   1.2 Salinity
   1.3 Temperature
   1.4 pH
2. To design an aquaponics model that incorporates a smart system for tilapia production;
3. To implement a web-based smart aquaponics system to facilitate fish growth;
4. To evaluate the system's performance based on quantitative and qualitative processes.

3. METHODS

3.1 Research Design

The research design that is applicable in the project study is the Developmental Research Design. The project designed is the combination of aquaponics system and IOT technology. Maintaining good water quality within the aquaponics system is the fundamental to well-being, sustainability, and success of the system. It is necessary to understand the water condition required in each part of the system and how these parameters can be monitored and adjusted when necessary to maintain the well-balanced system. There are plenty of parameter involved but four key water quality parameters are special importance to follow closely and erven online monitoring: 1) Water level 2.) Water acidity/ basic of the water (pH) 3.) Water temperature 4.) Salinity. In addition, we also aided the laborious the manual and daily feeding and added the fish feeding system – which supplies a fixed amount of food and fixed interval of time with the aid of timer and motor.

3.2 Project Design

As seen in Fig. 2, pumps, turbines, an oxygen generator, and a feeding system are all part of the system, along with sensors such as a dissolved oxygen sensor, a water temperature sensor, a pH sensor, and a conductivity sensor.

The Arduino, as the central processor, processes all the programming and collects all the data, which it then sends to the Raspberry to upload to the Google Firebase cloud, where analytics and monitoring take place.

As seen in Fig. 3, the data is first collected from the sensors, which include a dissolve oxygen sensor, a water temperature sensor, a pH sensor, and a conductivity sensor. Then, using the Arduino board, monitor and operate the system by activating essential control relays such as a pump, oxygen generator, and heater based on the measured data. The collected data is then sent to an IoT cloud sensor for analysis and presentation.

3.3 Project Development

First step of doing this project study is the fishpond examination, during which the researchers do the feasibility study and record at the place. The situation analysis is the second phase in constructing this project research. At this step, the researchers gather pertinent data by pre-survey and interview the local farmer about the issue and hearing their complaint and request to evaluate potential solutions. The third step is online research or surfing the internet. In this section, we discuss the resources required for our project study and how they will aid in the implementation of our research. The fourth step is data gathering, during which the researchers collect pertinent data and information from a variety of sources, and we obtain the aquaponics system and I.O.T. technology. The fifth phase is to develop the system design.

This is the section in which we will execute the system design by integrating the aquaponics system and IoT technology. Designing a system is a difficult undertaking since everything must be considered, including resources, budgets, sizes, the project's mechanism, and packaging. The sixth phase is programming both hardware devices and the IoT cloud platform, which involves writing the software necessary for the system to work. The seventh step is the construction of the project, during which the materials necessary to create a functional prototype are added. Testing is the eighth step. Additionally, testing, trial and error are required to determine whether the project is functioning properly. The last step is system evaluation, during which the project's performance, serviceability, aesthetics, and features will be assessed. The researchers will conduct a survey utilizing paper-based procedures such as questionnaires and personal interviews to get participants' thoughts.

3.4 Project Implementation

The study was carried out on a local farm. Deep water cultivation or rafting is used in the method. Floating planks or a flexible raft for pots capture holes. The roots of the plants are submerged in the dirt as they grow in these pots.

It's possible that the raft is floating straight on top of the fish tank. The system comes with a power outlet, a pump, turbines, an oxygen generator, a heater, and a feeding system that can be easily placed and installed. The control center, which included the Arduino, transistor control circuit, and Wi-Fi module, was mounted safely away from water and dust in a tiny box.

3.5 Project Setting

The study setting was conducted in a fishpond built specifically for the research endeavor along the Panhutongan, Placer, Surigao Del Norte coastline.

3.6 Project Evaluation

The researchers employ both quantitative and qualitative data. The quantitative emphasize objective measurement and the statistical, mathematical, or numerical analysis of data. Then qualitative used to evaluate the performance or acceptability of the system. It is to provide the researchers with the objective of determining the relevance or near-exact result of the study. The following is the data collection procedure:

As seen in Fig. 6, the block diagram shows the flow of the data collection procedure. First, we should identify the participants of the study. The data is being collected in terms of the system stability by comparing the value of standard parameters to the data gathered by the sensors and then the results are going to record then its average will be calculated. Through interviews, the researchers gather information and data from one of the project's stakeholders, the Bureau of Aquatic Resources. They also spoke with the fishpond owner about the state of their fish and some of the issues they faced. Following that the researchers focused their efforts on researching the components to be used and the circuit architecture for this project on the internet. When students are finished creating the project device, they must test it in the designated fishpond and keep track of the results.

The project study is going to be evaluated by the results that obtained from the process. And this process is the following to be evaluated in the project study:

1. Reliability - Are the values read by the sensors in this project study comparable to normal water parameter values?
2. Durability - How long and under what circumstances will the product function or last?
3. Effectiveness - Does the product successfully produce the desired output?

3.7 Participants of the Study

The project beneficiary, who includes the fishpond owner, is the major participant in this project research. An Electronics Engineer is required to assist the researchers in conducting the project study and ensuring that the project is properly implemented. Also needed are researchers who can study and design the product or technology.

Table 2. Participants involved in the project study

Participants	f(n=6)	% of Involvement
Farmers	2	20.00
BFAR	2	20.00
Aquaculturist	1	30.00
Electronics Engineer	1	30.00

Farmers, the Bureau of Fisheries and Aquatic Resources, aquaculturist, and electronic engineer must all take part in this study for it to be successful. Farmers have a 20% response rate because they will only supply a response if it is right. BFAR has a 20% participation rate because they will be conducting project inspections. Aquacultures have a 30% stake in the project, as she will check the growth, development, and production of *Oreochromis niloticus*. An Electronics Engineer has a 30% chance of being the one to fix the researchers' system. The preceding frequency table displays the number of participants and their participation rate.

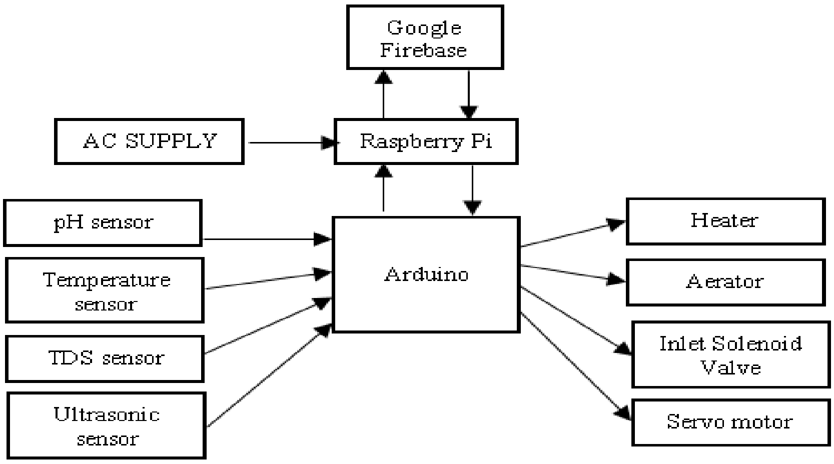


Fig. 2. Block diagram of the project

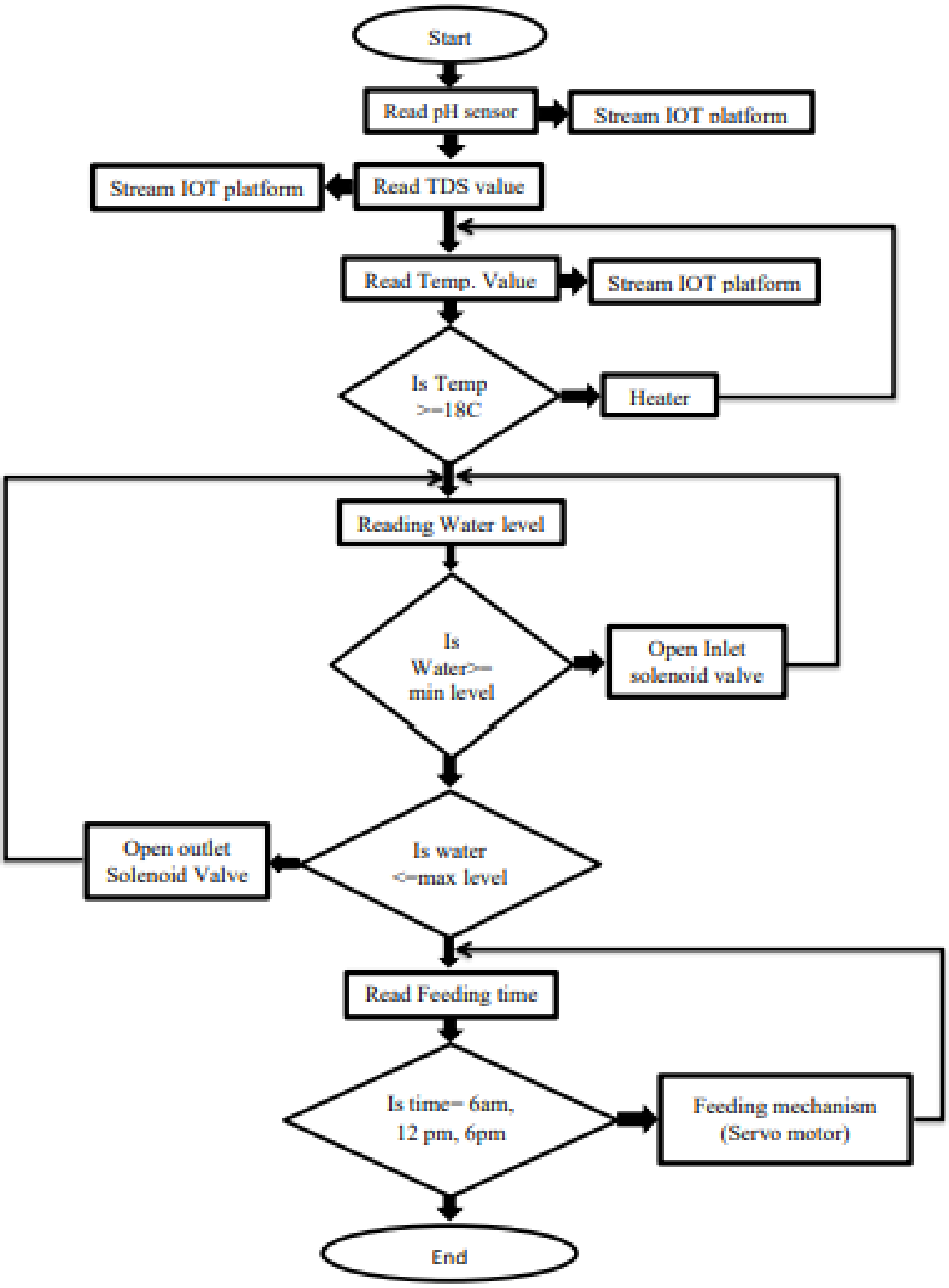


Fig. 3. Flowchart of the System

3.8 Instruments

As an IoT user, it's critical to understand the four pillars of the technology to reap the benefits that come with it: 1.) Device 2.) Data 3.) Analytics 4.) Connectivity

Multimeter is a device that measures voltage, current, and resistance.
Steel Tape Measure is a steel measuring tape is a flexible ruler used to measure distance.

Weighing Scale are devices used to measure the weight of single or multiple objects.

Digital Thermometer is used to verify a smart temperature transmitter under flowing conditions and a successful calibration of the smart temperature transmitter.

Ruler is used to measure the length in both metric and customary units.

Python Software creates communication of devices and software via wireless.

Node GS a back in process in sending and receiving Google Firebase.

C# is for creating a standalone GUI application.

C++ is used for Arduino coding.

3.9 Research Ethics

The researchers in this study follow the ethical criteria needed for performing their project study. To prevent plagiarism, the researchers examine intellectual property and supply correct recognition or credit for all research efforts. Second is to have cared for an animal in which researchers appreciate and care for animals when they are used in study. Finally, academics become socially accountable for promoting social good and avoiding or mitigating social harm via research, public education, and advocacy.

3.10 Statistical Tools

This project study uses mean standard deviation and frequency count as its statistical tool.

a. A frequency count is a measure of the number of times that an event occurs. It is usually used in the study to decide the number of participants who take part in the study.
b. The mean of a population is calculated by combining all the data points and then dividing the sum by the number of points. The formula is as follows:

$\bar{x} = \frac{\Sigma x}{n}$

c. The standard deviation is a measure of a set of values' variation or dispersion. The formula is said below:

SD = $\sqrt{\frac{\Sigma(x-\bar{x})2}{n-1}}$

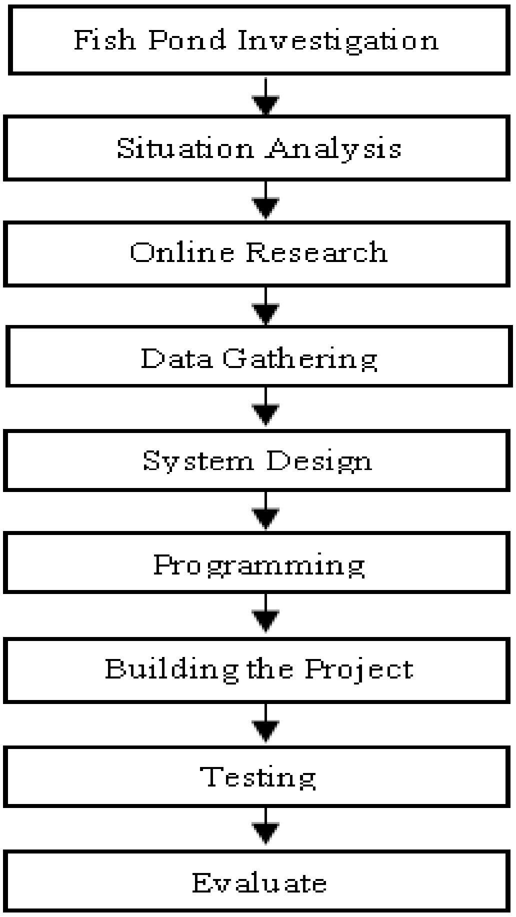


Fig. 4. Project Development Flow Chart of the Study

Fig. 5. Plot setting

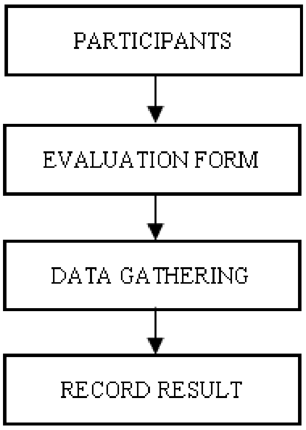


Fig. 6. Block diagram of data collection process

4. RESULTS AND RECOMMENDATIONS

4.1 Growth Parameters of Tilapia

The Table 3 shows the collected data growth of Tilapia:

The findings shown above write down that Tilapia comes in both big and small sizes and has been seen to grow every 2 days. Then, as we can see, there is 6% growth in both sizes in 27 days.

The image above was a sample actual pictorial of the two sizes of the fish, which are the large and small.

A maximum stocking density of 20kg/1,000 liters is the basis for the suggested fish density. Added aeration and mechanical filtration can result in higher densities, but beginners should avoid doing this (Cohen, Stankus 2014). In our case, we build an Aquaponics unit with a density of 363.05 liters that can be used to store a sample of 7.26 kg of fish stocks if used as directed. The biological activity of the nitrifying bacteria and their ability to transform ammonia and nitrite are influenced by the pH level of the water. Because the pH is 8.56, which shows that there is more ammonia present, it is recommended that the water be passed through both mechanical and biological filters. The water is fresh since its salinity level, which is measured as an average of 210.550, did not exceed the threshold of eight hundred parts per million (ppm), which defines salt water. The temperature is 28.25 degrees Celsius, which is within the range in which Tilapia may survive and thrive.

Table 3. Growth length of tilapia every 2 days

Day	Large Fish		Small Fish	
	Length (in.)	Variance	Length (in.)	Variance
1	6.5		4.5	
3	6.8	0.3	4.8	0.3
6	7.2	0.4	5.1	0.3
9	7.4	0.2	5.4	0.3
12	7.7	0.3	5.7	0.3
15	8.0	0.3	6.0	0.3
18	8.3	0.3	6.2	0.2
21	8.6	0.3	6.4	0.2
24	8.9	0.3	6.7	0.3
27	10.1	1.2	6.9	0.2
	Average:	0.40	Average:	0.27
	%	6.15	%	6.00

Fig. 7. Actual captured size of the fish

Table 4. Parameters of the water

Water Parameters	Standard	Study
Water level / Depth	Stocking Density = 20kg/1000 liters	22,155 cubic inches 363.053 liters 7.26 kg of fish stocks
pH	6-9	8.56
Salinity	0-800 ppm	210.550 ppm
Temperature	18-30°C	28.255°C

4.2 Design of Aquaponics Model Utilizing Smart System

The Arduino Mega is a microcontroller module based on the ATmega 1280 (datasheet).

Fig. 8. Arduino mega

Fig. 9 - Raspberry Pi 3 model B+

The Raspberry Pi is a dual band wireless LAN, Bluetooth 4.2 / BLE, faster Ethernet, and Power-over-Ethernet support (with separate PoE HAT).

Fig. 10. Ultrasonic sensor

Ultrasonic sensor is an electronics device that uses ultrasonic sound waves to detect the distance between a target item that reflecting sound into an electrical signal.

Fig. 11. Relay Module

The Relay module is a separate piece of hardware that allows you to control remote devices.

Fig. 12. Servo motor

A Servo motor is a shut servomechanism that regulates its movement and end position through position information.

Fig. 13. TDS (Total Dissolved Solids)

A Total Dissolved Solid (TDS) is a device to measure the dissolved combined content of all inorganic and organic substance present in the liquid molecular.

Fig. 14. pH sensor

A **pH sensor** is a schematic device used to accurately measure acidity and alkalinity in water and other liquid substances.

Fig. 15. Temperature Sensor

A Temperature sensor is an instrument used to measure the degree of hotness or coldness and converts it into a readable unit.

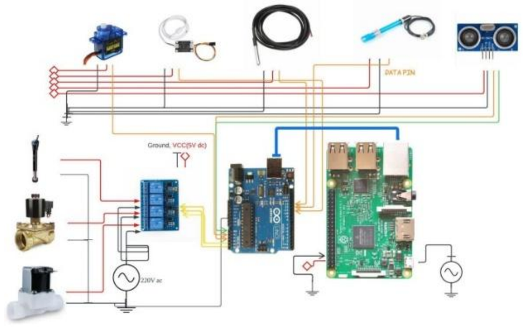


Fig. 16. Schematic Diagram

The Schematic Diagram shows the wiring placement and different materials of the project.

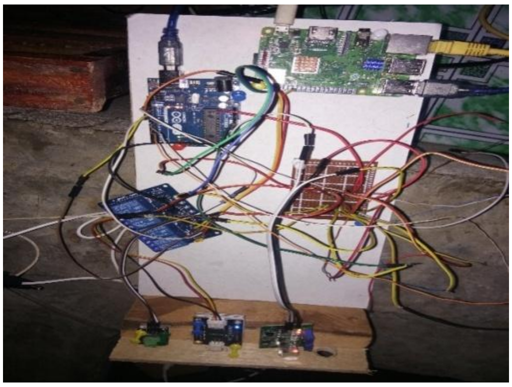


Fig. 17. Actual schematic diagram

The Fig. 17 shows the actual connection of every major part of the schematic diagram.

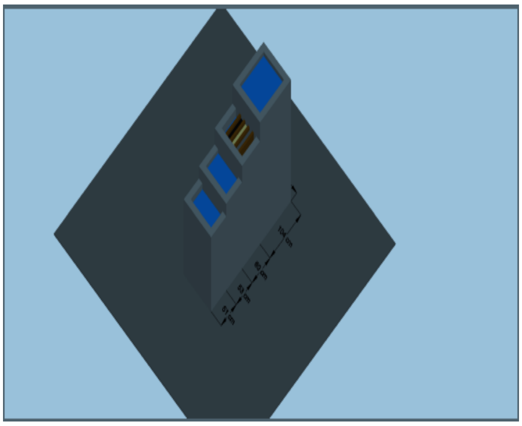


Fig. 18. Isometric view

The isometric view of the planned fish tank is depicted in the Fig. 18. To lessen the need for water pumps, a gravitational force is applied by the tank's design. To return the water to the main tank, only one water pump has been used for the final tank, as opposed to the earlier four.

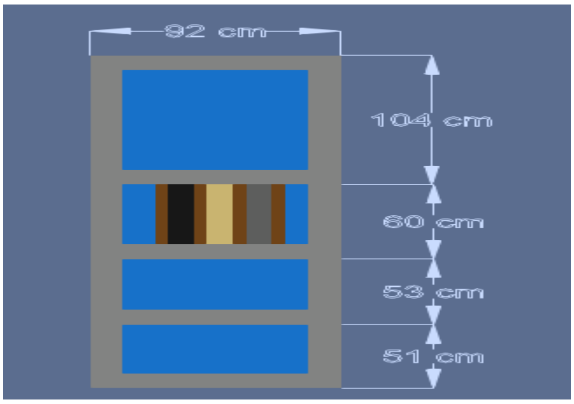


Fig. 19. Top view

The Fig. 19 shows the top view of the designed fish tank showing also the dimensions of every tank.

The Fig. 20 shows the dimensions of the fish tank in a right-side view with the legend to fully understand each part of the dimensions.

The Fig. 21 shows actual representative for the top view of the tank designed.

The Fig. 22 shows the actual representative for the isometric view of the designed tank.

4.3 Web-based Implementation for Smart Aquaponics System

The diagram above displays the structure of a smart aquaponics system. Owing to its precise signal timing and data extraction from sensors, the main microcontroller is an Arduino Uno. Our connection between the local hardware and the cloud database (Google Firebase), which is connected wirelessly via built-in Wi-Fi, is made through the Raspberry Pi. The heater, servo motor, and inlet/outlet solenoid valve are some of our actuators. Our primary sensors are the DS18B20 temperature sensor, Total Dissolved Solids, pH 4502c (pH sensor), and ultrasonic sensor. Users can access the streamed data analytics through a tailored application.

The flowchart above illustrates the security protocol and model used while sending or receiving data to and from the cloud database (Google Firebase). To make sure that only authorized users may access data, the system uses authentication. The protocol begins at Google Firebase. Firebase restricts access to a few registered users who require access to personal data for work-related reasons. The process continues to the parent target name, which adds the child data, if the authentication is successful. If not, if the command is present in the command table, it at once executes the check command. At that point, if empty, it comes to a stop.

The Fig. 25 demonstrates an example of how a user could interact with a Smart Aquaponics System for the Application and Database of *Oreochromis niloticus* Production. The four pages of the program include its function. The user must first log in to the system by entering their account name and password for the system to confirm that they are permitted users. The user can quickly access the analytics of the real-time data streams of the water parameters using the Home GUI and if the parameters exceed to the normal range the system automatically send alert to the users via email and SMS, which is presented next. The user can quickly download and import the cloud-saved data from this page into MS Excel for further study. On the calibration, the user can also check to see if the sensors are still working.

The above sequence diagram visually illustrates the interaction and cooperation between the user and the Smart Aquaponics System. It provides a comprehensive overview of the system components, functions, and processes involved in each transaction. The system comprises four key objects and functions. To begin with, the sign-in function demonstrates the collaboration between the application and the cloud, utilizing conditional statements (if-else) to authenticate user access. The Home GUI function integrates four objects: the application, the cloud, sensors, and actuators. In addition, it offers real-time parameter data display and automatically sends email alerts to the owner if water parameters exceed their normal range. Furthermore, this function serves as the central hub of the system, enabling users to monitor and control the aquaponics system effectively. The data summary transaction facilitates the direct import and download of data from the cloud for further research purposes. Both the application and the cloud collaborate to enable seamless data access and analysis, enhancing the system's capabilities. Finally, the settings transaction provides a platform to view the active actuators and verify if the sensors are operating within the calibrated range. This function ensures the proper functioning of the system by allowing users to monitor and adjust system settings as needed. In summary, the sequence diagram not only illustrates the user-system interaction but also provides valuable insights into the underlying components and processes. It highlights the seamless integration of the application, cloud, sensors, and actuators, and showcases the system's features such as real-time monitoring, data analysis, and system configuration. It is the last transaction.

The first step in using the system is to access the opening page, as seen in the image above. Here, the system will decide if the user has permission to use and access the system. On the right side, the registered user's username and password must be typed. The process for creating an account and completing the form for a new user is on the left side.

The illustration above shows that you have already entered your account and can start keeping track of your tank's water condition. Additionally, this section displays the water status of your tank, and if any parameters are outside of the normal or acceptable range, the color changes to red and the owner is at once notified through email or SMS.

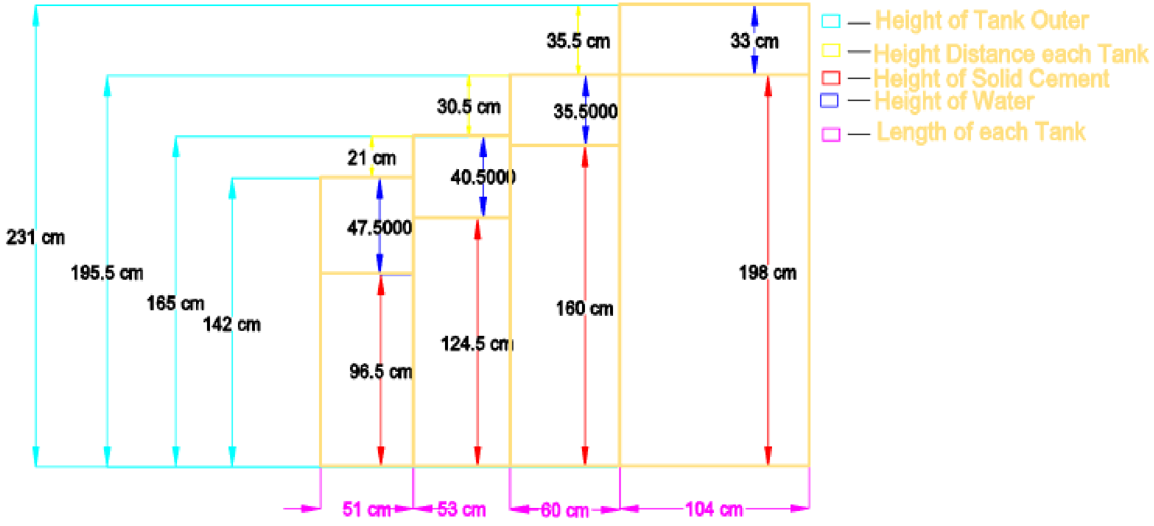


Fig. 20. Dimensions of the Tank

Fig. 21. Actual top view

Fig. 22. Actual isometric view

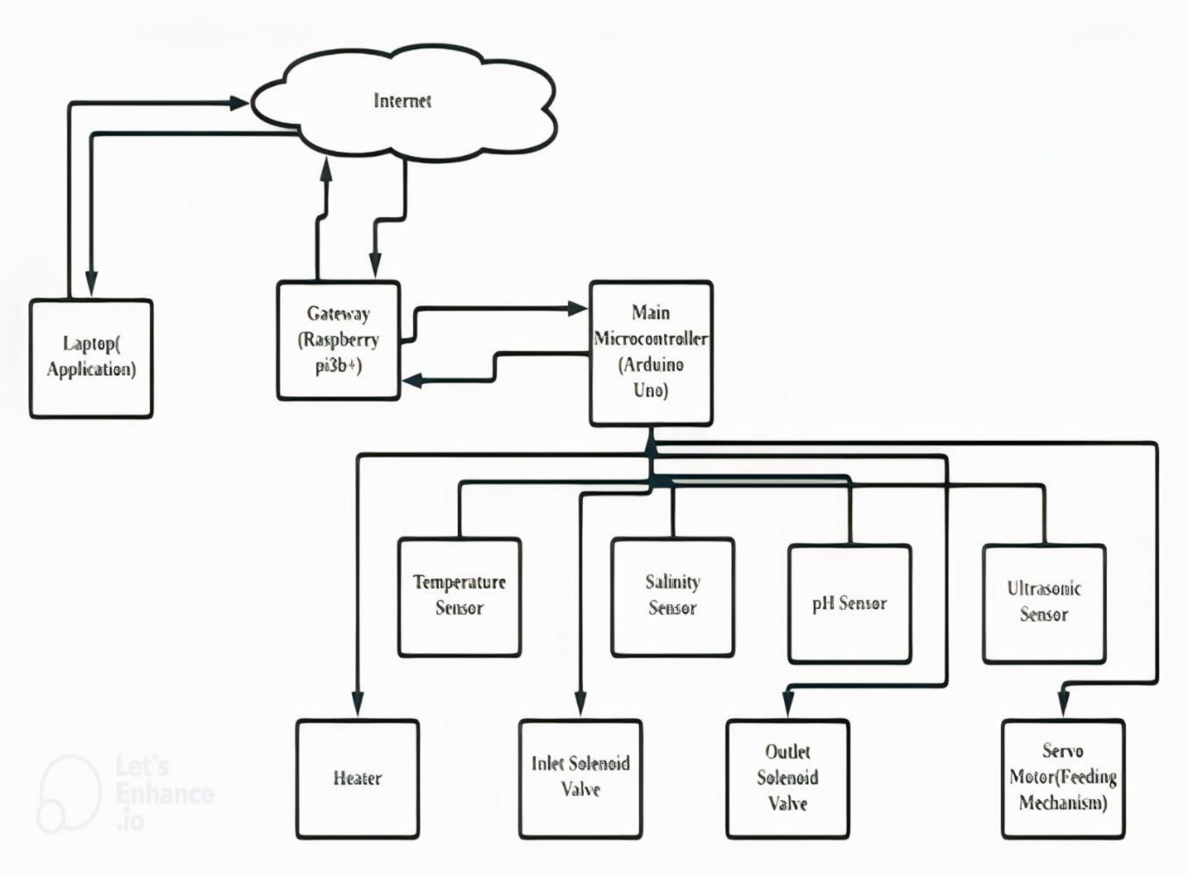


Fig. 23. Set - up diagram

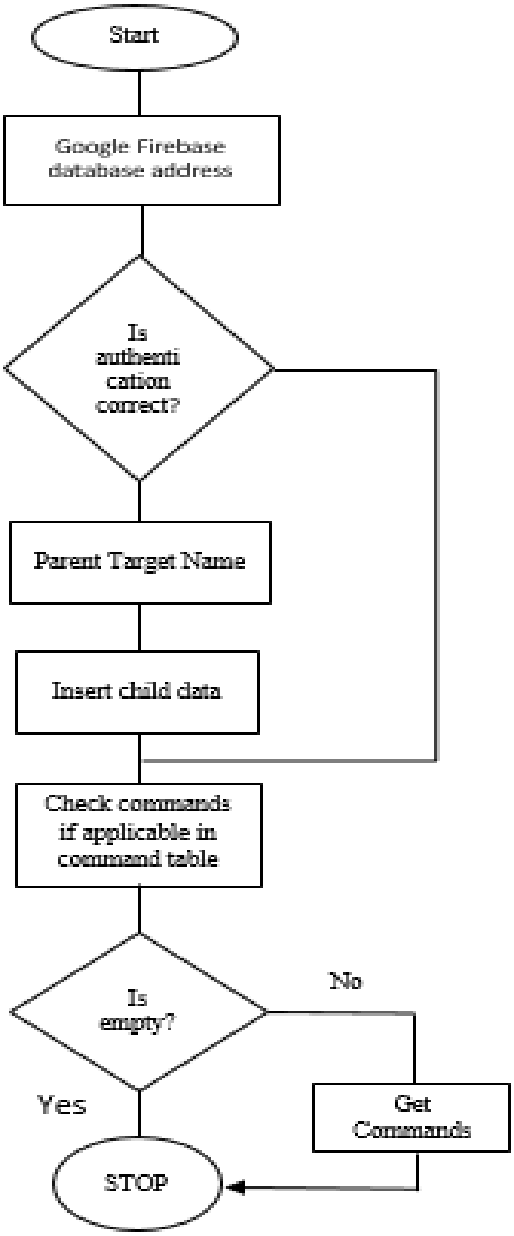


Fig. 24. Flowchart of the web-based design

The data overview of all the sensor readings, which were taken every three seconds, is shown in this picture. Additionally, if the owner wants to check the water's condition again later, they will need this information for future reference. You may get this data summary in spreadsheet format as well.

The application's settings are displayed in the figure for this part. In this setting section, you can adjust the application's calibration and decide whether the system is still functioning normally.

The final figure depicts the application's owner, along with their names, titles, and email addresses for easy contact.

4.4 Quantitative and Qualitative System Evaluation

The Table 5 shows the overall power consumption of the system which only has 193 watts.

The above tables were the evaluation results, which showed that this study received a rating of "very acceptable" in overall results from the evaluators.

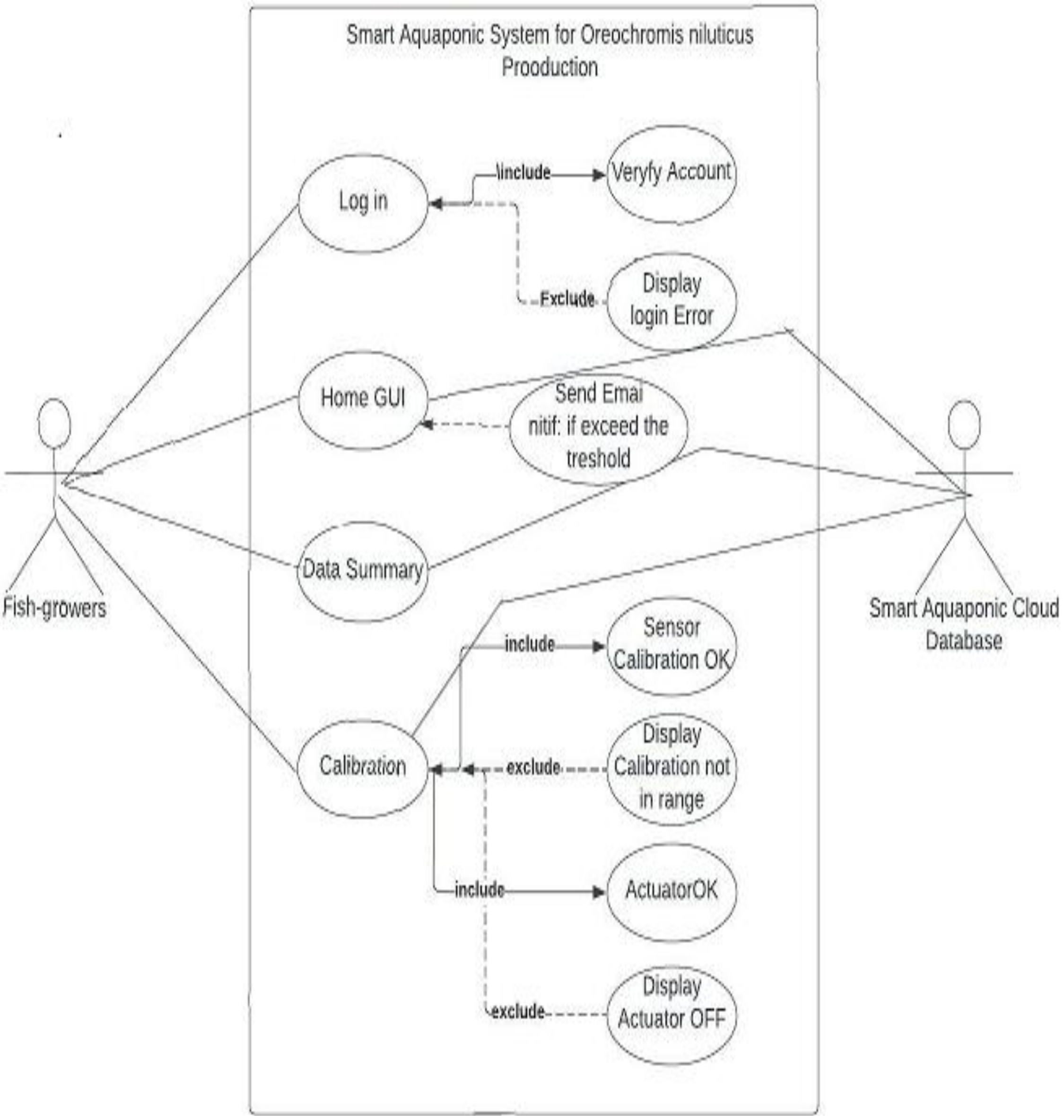


Fig. 25. Use case diagram

Table 5. Hardware requirement of the system

Part	Voltage (V)	Current (A)	Power (Watts)
Raspberry Pi	5.1V	2.5	12.75
Arduino Uno	5V	1	5
Temperature Sensor	5.5V	0.001	0.0055
TDS Sensor	5V	0.006	0.03
pH Sensor	5V	0.002	0.01
Ultrasonic Sensor	5V	0.005	0.025
Inlet Solenoid Valve	12V	2.80	30
Outlet Solenoid Valve	12V	3.33	39.96
Heater	220V	0.23	50.6
Aerator	220V	0.022	4.84
Servo Motor	5V	0.0010	0.005
Relay Board	5V	10	50
Total Power			193 watts

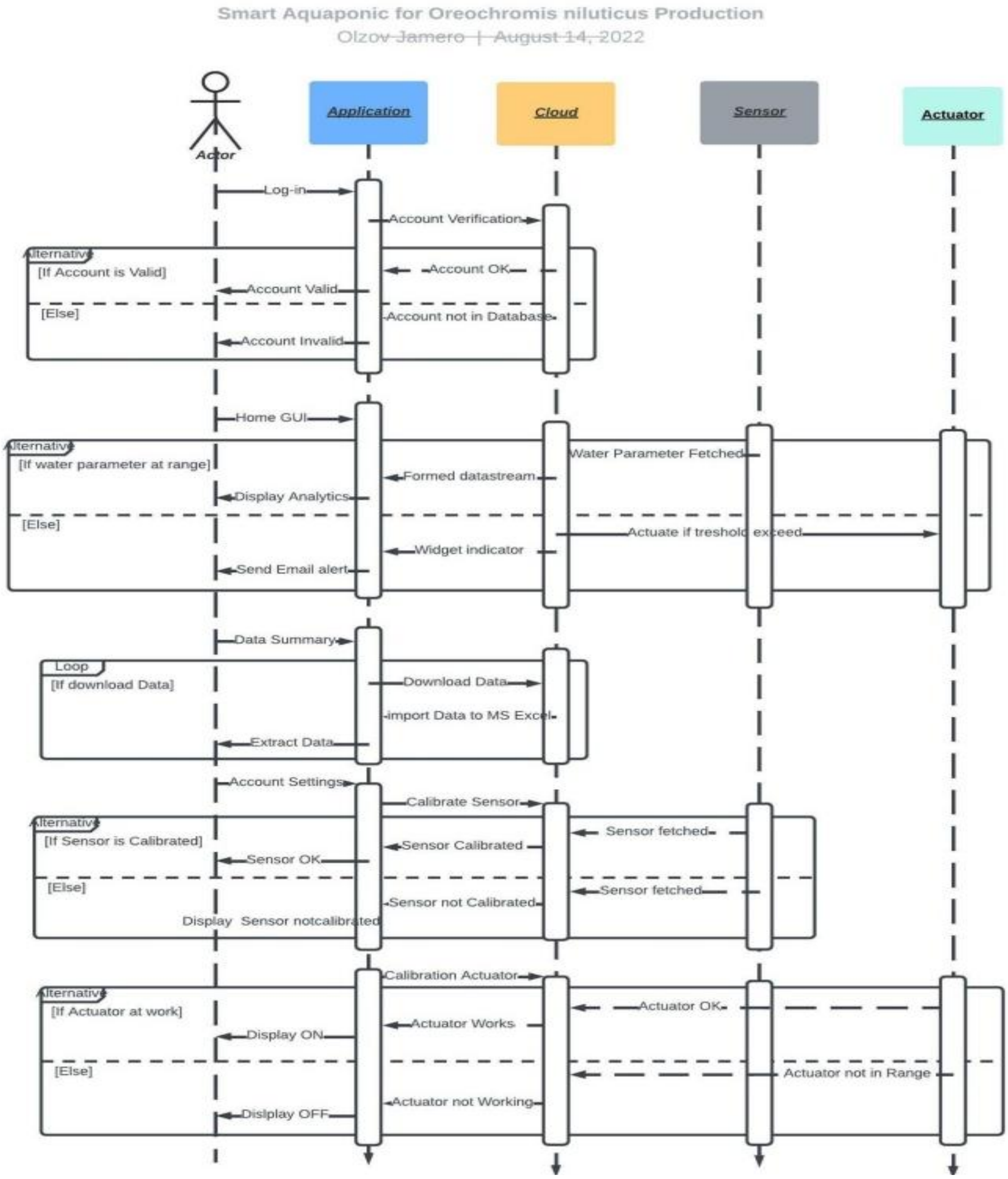


Fig. 26. Sequence diagram

Table 6. System performance acceptability survey

Parameters	**m**	**SD**	**Qualitative Description**
Reliability			
1. The sensors run accurately during the testing period.	4.83	0.75011	Very Acceptable
2. The fish feeder runs properly during the exact time scheduled.	4.50	0.8367	Very Acceptable
3. The smart aquaponics app constantly checked the water parameters.	5.0	0	Very Acceptable
Average	4.78	0.5289	Very Acceptable

Parameters	m	SD	Qualitative Description
Durability			
4. The system applies wiring proper installations.	4.83	0.7528	Very Acceptable
5. The circuit is protected in good casing.	4.50	0.7528	Very Acceptable
6. The system applies cooling system.	5.0	0.8944	Very Acceptable
Average	4.78	0.8	Very Acceptable
Effectiveness			
7. The smart aquaponics ensures the growth of the fish.	4.17	0.5164	Acceptable
8. The smart aquaponics app monitoring consistently ensures the water parameters for the fish growth.	3.17	0	Moderate Acceptable
9. The water circulation of the tank removes the contaminants from the water.	3.00	0.5916	Moderate Acceptable
Average	3.45	0.3693	Acceptable

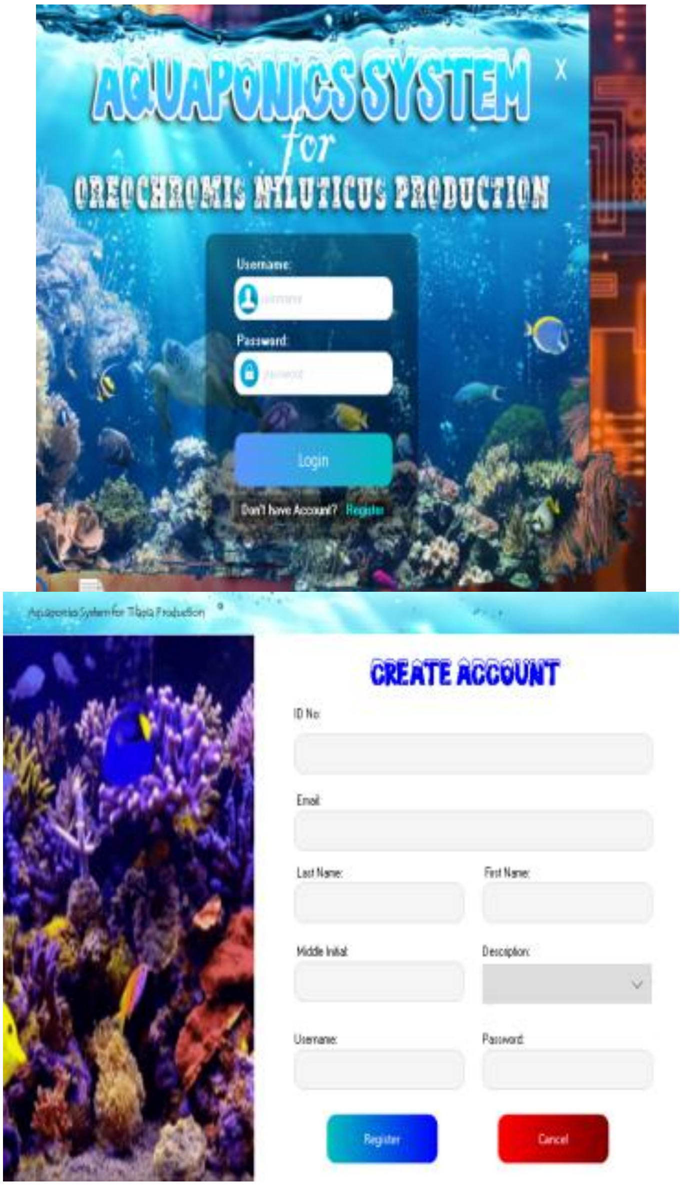
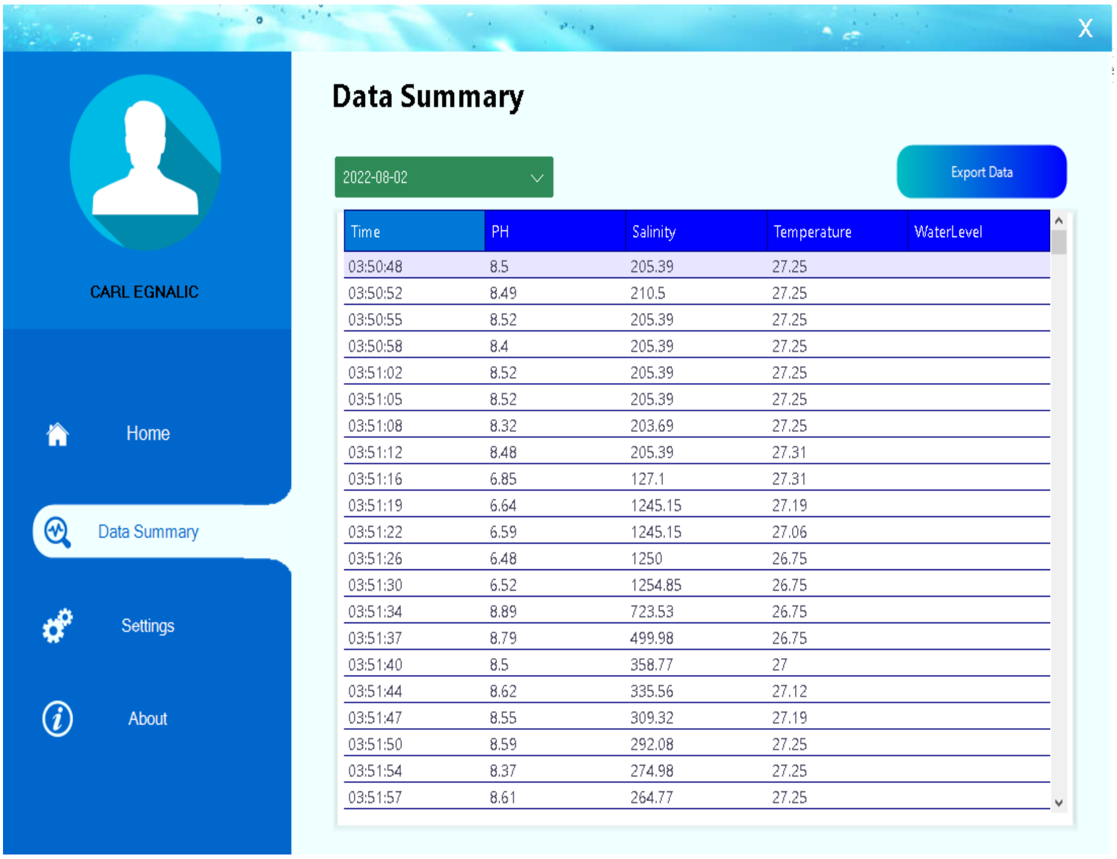


Fig. 27. Software initial page

Did you know?

800ppm (parts per medium) is the acceptable max value reading for tilapia production. pH Level reading must in range of 6 to 7 and water temperature must play at 18 to 30 degree Celcius

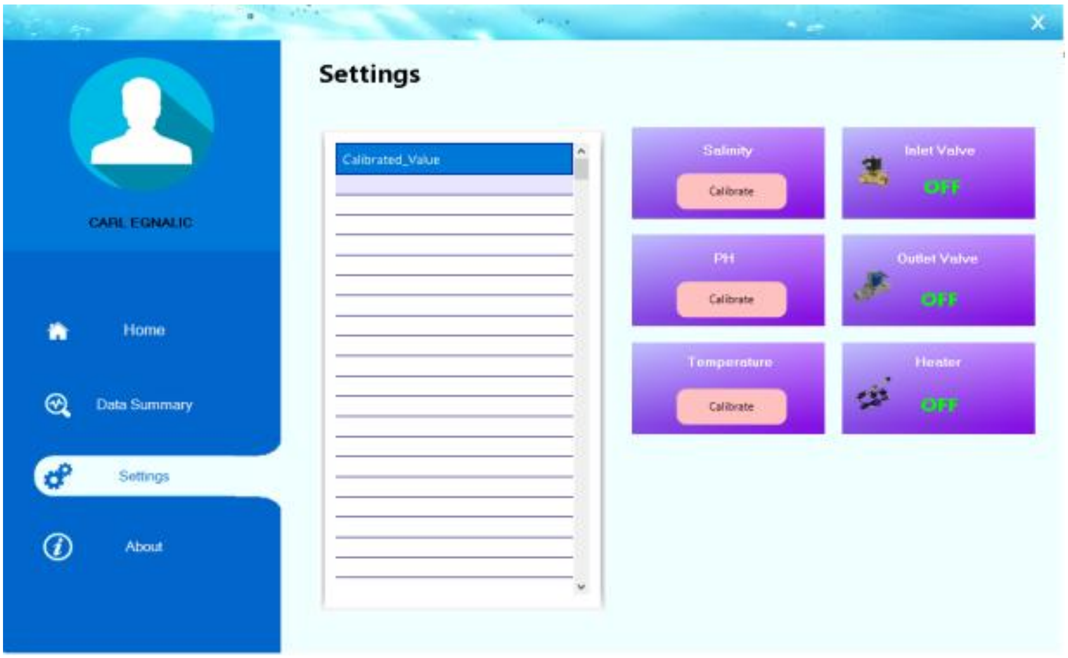
Fig. 28. Software home GUI



2022-08-02

Time	PH	Salinity	Temperature	WaterLevel
03:50:48	8.5	205.39	27.25	
03:50:52	8.49	210.5	27.25	
03:50:55	8.52	205.39	27.25	
03:50:58	8.4	205.39	27.25	
03:51:02	8.52	205.39	27.25	
03:51:05	8.52	205.39	27.25	
03:51:08	8.32	203.69	27.25	
03:51:12	8.48	205.39	27.31	
03:51:16	6.85	127.1	27.31	
03:51:19	6.64	1245.15	27.19	
03:51:22	6.59	1245.15	27.06	
03:51:26	6.48	1250	26.75	
03:51:30	6.52	1254.85	26.75	
03:51:34	8.89	723.53	26.75	
03:51:37	8.79	499.98	26.75	
03:51:40	8.5	358.77	27	
03:51:44	8.62	335.56	27.12	
03:51:47	8.55	309.32	27.19	
03:51:50	8.59	292.08	27.25	
03:51:54	8.37	274.98	27.25	
03:51:57	8.61	264.77	27.25	

Fig. 29. Software data summary

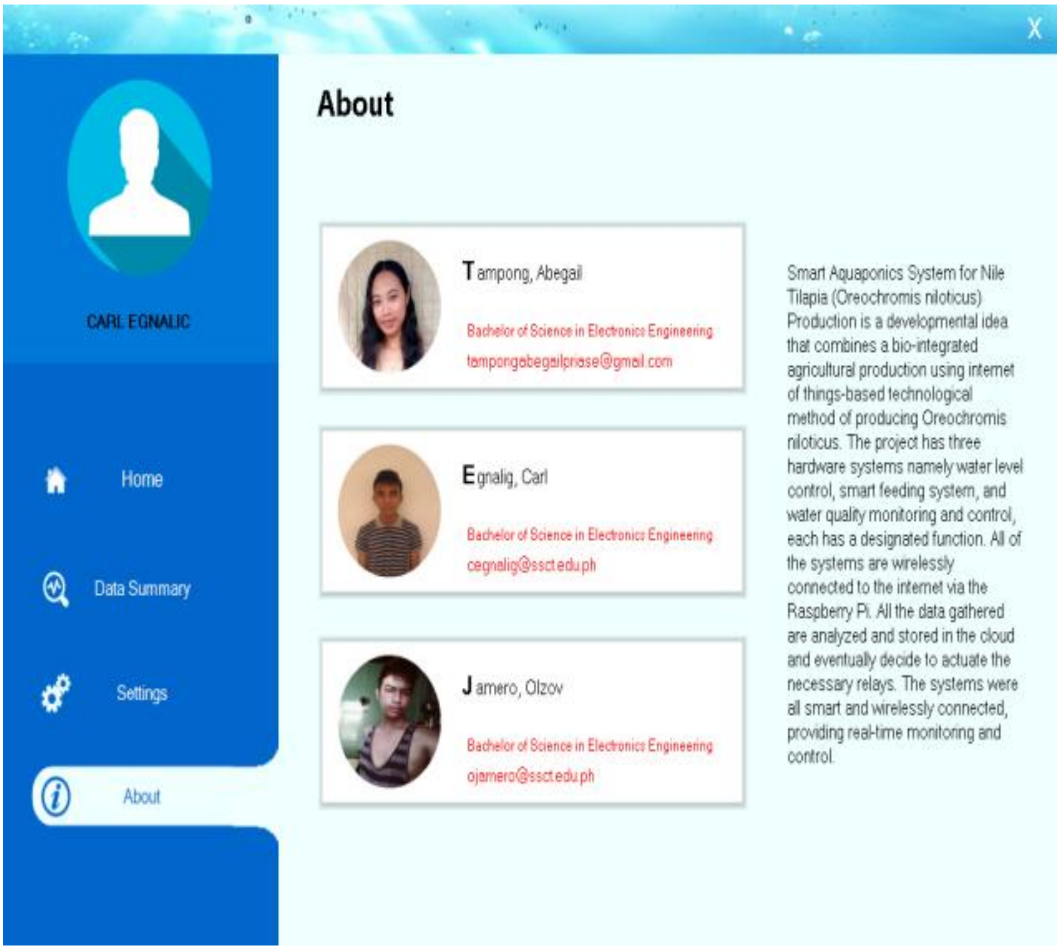


Inlet Valve OFF

Outlet Valve OFF

Heater OFF

Fig. 30. Software account settings



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Smart Aquaponics System for Nile Tilapia (Oreochromis niloticus) Production is a developmental idea that combines a bio-integrated agricultural production using internet of things-based technological method of producing Oreochromis niloticus. The project has three hardware systems namely water level control, smart feeding system, and water quality monitoring and control, each has a designated function. All of the systems are wirelessly connected to the internet via the Raspberry Pi. All the data gathered are analyzed and stored in the cloud and eventually decide to actuate the necessary relays. The systems were all smart and wirelessly connected, providing real-time monitoring and control.

Fig. 31. Software about section

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Conclusions are drawn based on the results of the study. The study concludes that the Smart Aquaponics System for *Oreochromis niloticus* Production is a recirculating aquaponics system that employs IoT technology to monitor and regulate fish development factors such as pH, salinity, total dissolved solids, temperature, and tank water level.

The system is made up of hardware components including the Raspberry Pi, Arduino, sensors, and actuators, as well as software components like a cloud-based IoT platform, a mobile app, and a web-based dashboard.

The method was able to promote large Tilapia growth within the tank while keeping fish development criteria. The system consumes extremely little electricity and was rated "very acceptable" based on quantitative overall findings. To enhance the device, the researchers suggested adding an x-ray camera, dissolving oxygen, and a camera module for live monitoring.

The researchers used mean, standard deviation, and frequency count as statistical tools to analyze the data collected from the study. The tables and figures provide information on the hardware and software requirements of the system, growth parameters of Tilapia, and data summary of all the sensor readings.

It is also concluded that the Arduino microcontroller successfully maintained the operations of the system as designed while the Raspberry Pi microcontroller consistently gathered periodic data and displays real time results of the parameters being monitored.

The smart aquaponics application software can also be concluded to work well with the microcontroller operation and give alert through email or SMS if the monitored parameters were exceeded to the normal level. The data extracted from the system were recorded efficiently for future analysis. The application is simple and conveniently to use by the users.

And lastly, it is concluded that the smart aquaponics system uses very minimal power for operation and has a rating of very acceptable based on the quantitative overall results.

5.2 Recommendations

Moreover, the researchers made the following recommendations:

1. Add an x-ray camera so that the size of the fish may be determined automatically.
2. It is recommended to add dissolved oxygen since it is necessary.
3. Adding a camera module to provide live monitoring.

ACKNOWLEDGEMENTS

The accomplishment of this project study was accomplished due to the assistance and cooperation of several individuals. The researchers would like to convey their thanks and appreciation to everyone who contributed to the successful completion of this project study proposal. To begin, the researchers give thanks to the Almighty God for the knowledge, strength, patience, good health, and direction granted the researchers unreservedly. Without Him, this project study proposal will not be possible. To the researchers' adoring parents: Mr. and Mrs. Egnalig, Mr. and Mrs. Jamero, Mr. and Mrs. Tampong, and their families, for their financial, emotional, and spiritual support. The researchers would also like to thank their research adviser, R.R. Bacarro, and their program chair, VJ.V. Ylaya, who supported and directed them throughout their research project. Engineering professors, students, and friends who always provided them delight, inspiration, and motivation during times of adversity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Access on Jun. 16, 2023

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/101041