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Assessment of an automated IoT-biofloc water quality management system in the *Litopenaeus vannamei*'s mortality and growth rate

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ABSTRACT
Climate change greatly influenced aquaculture in the Philippines and the deteriorating water quality; in effect, fish production reduced drastically. Thus, fish farmers and aquaculture researchers have been searching for innovative technologies to address these issues. One technology is the biofloc systems. This technology uses a zero-water exchange and accumulates microorganisms that serves as a food source. In the biofloc, water quality management is highly recommended. This study aimed to assess the technical and operational effect on the shrimp growth and survival of the developed automated water quality management internet of things (IoT) system in a biofloc system. The hardware prototype comes with a mobile application which has features namely: account management, fish/shrimp profile, water quality management, auto feeding and manual controls. This study conducts experimental research which assessed the impact of an indoor pond biofloc with the developed prototype on the *Litopenaeus vannamei*'s growth and survival rates. Results were favorable to the biofloc system with the developed prototype, having a 10% higher survival rate and 3.2% higher growth rate, compared to the traditional recirculating aquaculture systems. Adapting the biofloc and the IoT prototype, a fish farmer may earn P78,300 pesos for each white leg shrimp (*Litopenaeus vannamei*) harvesting period.

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KEYWORDS
Water management; biofloc; internet of things; *Litopenaeus vannamei*; growth rate; survival rate

1. Introduction

Aquaculture and capture fisheries are essential sources of food and income [1]. The Philippines, world's second-largest archipelago located in Southeast Asia and the westernmost Pacific Ocean, is considered a mega-diversity country because of its great diversity of habitats, fishes, and other genetic resources [2]. In terms of money and employment, the Philippines' fisheries contribute significantly to the national economy. In 2015, total fish production was predicted to be 4.65 million metric tons, with the fishing industry contributing over $4.33 billion to the country's gross domestic product (GDP) [3,4]. Moreover, the fishing sector employed an estimated 1.6 million people across the country and contributed 1.5% to GDP [3–5]. Despite a large amount of fish production presented, the Philippines is vulnerable to climate change. This climate change impact leads to an economic shock in the nation's economy [4,6,7].

Climate change is projected to exacerbate the poor's predicament in the Philippines, which is already aggravated by the slow growth of fisheries and the poor's reliance on the industry. Furthermore, the negative economic impacts on the fisheries sector may create a vicious cycle in which fish abundance and location changes cause more competition and conflict for the remaining resources [4]. With the climate change issues in fish/shrimp farming, experts investigated other aquaculture approaches: indoor farming and the integration of advanced technology such as internet of things (IoT) and biofloc. In a warming world that is rapidly experiencing food shortages, it is imperative to use technology like IoT to produce more foods sustainably faster [8]. IoT technology has taken the world by storm. Established players and startups take advantage of IoT's power to develop technologies that pull data from different sensors. The vast data obtained from sensors to manage the processes are used to make aquaculture operations more effective and environmentally friendly using cloud-based analytical tools [9].

Biofloc technology was created in the 1990s to help fish and shrimp growers save money on feed by reusing wastewater during production. The basic idea is those producers can take advantage of the nitrogen cycle by allowing beneficial bacterial colonies to flourish in culture water [10]. Biofloc fish farming is one of the most effective ways available today to assist fish farmers in achieving various goals, including high output, cheap cost, sustainable growth, improved revenue

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opportunities, reduced land and lower maintenance costs [11]. However, this new aquaculture production system entails a complex process, particularly in managing the water quality [12]. Among the significant water parameters which needed quality management includes pH, dissolved oxygen and temperature [13].

The target species in this study is the *Litopenaeus vannamei*, more popularly known as pacific white shrimp or white leg shrimp. For health and development, shrimp need good water quality regardless of the method used. Like other aquatic species raised at densities greater than natural, shrimp influence the water quality in which they live. Controlling this atmosphere to keep it in good shape decreases tension, promotes productivity and lowers the risk of death. Owner/operators must handle these criteria hourly, monthly or weekly and should have proper facilities and equipment [14]. This complex water quality management process that needs to be considered in culturing *Litopenaeus vannamei* and looking into biofloc technology, which is found to be sustainable, is a virtuous avenue to explore and a challenge faced in this study.

The IoT spreads its wings across all areas and alters industry and lifestyle usage. It saves energy and improves the reliability and connection of data available worldwide [15]. The ability to monitor and assess water quality in real-time is the most significant advantage of IoT in this field. At any given time, the state of the water quality (based on various indices) can be obtained. This is made possible by the speed of internet communications, which allows data from sensors to be delivered in fractions of a second. Traditional water quality monitoring cannot achieve these remarkable speeds [13]. A study by Nayak et al. [16] where an IoT design aims to predict the possible abnormalities in the water quality was developed [16]. With this related study, the researcher saw an opportunity for the application of IoT technology to ensure that the water quality is well managed in biofloc indoor tank systems and taking into consideration its effect on the specie rate of survival and development. Studies for IoT development in aquaculture were mostly seen by the researcher in a recirculating aquaculture system (RAS) setup; however, throughout the duration of this study, the researcher found no similar works particularly on the biofloc operation.

The study's main objective is to assess the impact of the automated IoT remote water quality management in a biofloc production system on shrimp growth and survival rate. The study aimed to identify the significant effect of the designed and developed automated water quality management system in a biofloc production system on the growth and survival rate of a shrimp species. Thus, quantitative experimental research was conducted, focusing on the assessment of the technical and operational aspect of the shrimp growth and survival in an automated water quality management system for biofloc production vs. the traditional RAS. The experimental process includes biofloc preparation, appropriate feeding rate, water management process, growth performance and statistical analysis.

The prototype design consists of a mobile app and a hardware-controlled system. The android mobile app has an account management module, specie profile, telemetry and manual controls. It serves as a user interface where the user may read sensor (pH, temperature and dissolved oxygen) readings and receive alert notifications remotely. Alert level values in the proposed system are set in the administrator account; this is the user in charge of managing the system. It is also in the mobile app where a user can set a feeding schedule. The mobile app interacts with the hardware, which consists of an Arduino, raspberry pi, sensors and relays. Sensors connected to the Arduino are pH, temperature and dissolved oxygen. Once the Arduino detects unacceptable reading levels from the sensors, a corresponding relay is automatically activated [17].

The study did not cover the installation of a security system against any attacks or intrusion. Data analytics, application of artificial intelligence and related reports were also not included in the study. Likewise, the carbon to nitrogen ratio monitoring and automating floc level in the tank were not considered. Furthermore, the feasibility study did not include the financial impact and identification of the business model appropriate for the project.

2. Materials and methods

2.1. Conceptual framework

Presented in Figure 1 is the adapted three-layer IoT architecture [18] of the automated IoT water quality management system designed and developed in this study. This architecture consists of three layers, namely, the physical, middleware and application layer.

The physical layer contains all the physical components in the prototype. These layers component includes the sensors, relays, Arduino and raspberry pi controllers, voltage regulators, connectors, power supply, solar panel, solar charge controller and battery.

On the other hand, the middleware IoT layer provides services for storage and processing the communication between the physical and application layers and among the sensors and actuators in the IoT infrastructure. In the design of the IoT system, a cloud database was created and hosted in x10hosting.com. Moreover, the cloud database was configured with alert values and interacts with the mobile app to send sensor values from the hardware prototype.

Finally, the application layer is where the development of the mobile application is classified. The android mobile application which includes dashboards for the fish/shrimp profile, telemetry, manual controls, and

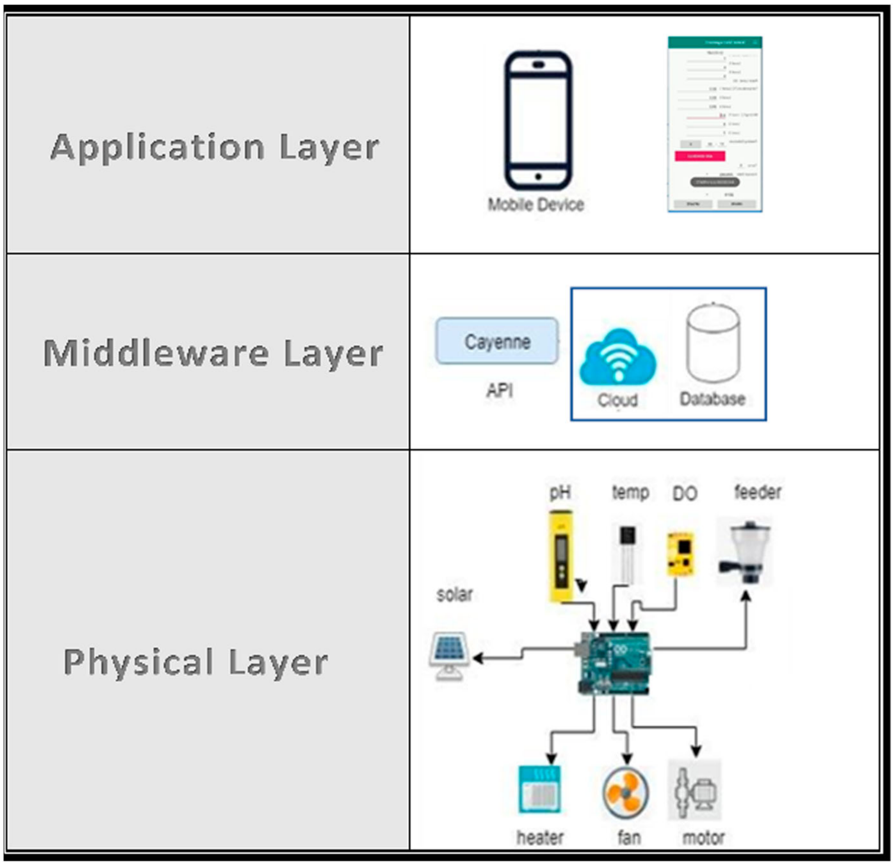

Figure 1. Three-layer architecture [17].

support are components in this layer. Major functionalities in the mobile app and categorized in this layer are setting alert values in the mobile app, displaying sensor values in graphical form, and manual controls on the relay where pump, heater, fan and feeders are connected [17].

2.2. Project technical description

The project's intent was to manage water quality and provide automated feeding in an indoor biofloc tank system. Dissolved oxygen, temperature and pH sensors are the water parameters to be managed. Relays, connected to its corresponding peripherals, are used to manage unacceptable readings in the sensors [17].

2.2.1. Hardware platform assembly

The network diagram (see Figure 2) presents the layout of the component's connection in the study. The Arduino ATMEGA 2560 controller serves as central connection to all the other peripherals such as the relays, sensors and the solar panel system. The Arduino controller connects to a Wi-Fi router to send/receive alerts/notifications to the developed mobile app. With a wide range of boards, Arduino boards are one of the most in demand microcontrollers. The Mega 2560 is the Arduino board with the most pins, with 54 digital I/O pins (of which 15 are PWM- Pulse Width Modulation) and 16 input analogue pins. Moreover, the Mega 2560 has 8 kB of SRAM (Static Random Access Memory), which is 4 times more than the Uno and 3.2 times more than the Micro, and its price is affordable [19]. These are the factors why Arduino ATMEGA 2560 was chosen as the controller for this study.

Presented in Figure 3, circuit components were securely enclosed and wired in the project box. Communication is done via UART (Universal Asynchronous Receiver-Transmitter) mode, and results were displayed on the Arduino serial monitor. A single Arduino ATMEGA 2560 UART (Rx/Tx) serial port was expanded, so that multiple sensors can be connected. The Arduino's ATMEGA 2560 port is linked to the expander after which the signal was routed to the eight ports where the peripheral devices (sensors, relays, power input, charge connector and step-down regulator) were connected [17].

As shown in the schematic diagram (see Figure 4), the sensor (pH, DO-dissolved oxygen, and temp.) modules were connected to corresponding input pins in the Arduino module. DO and pH sensors used BNC (Bayonet Neill–Concelman) as its connector while temperature sensor was soldered directly to its sensor module. Solid state relays connected to corresponding power outlets where fan, heater and motors are to be connected. The positive port of the SSR (Solid State Relay) was connected to the Arduino module while

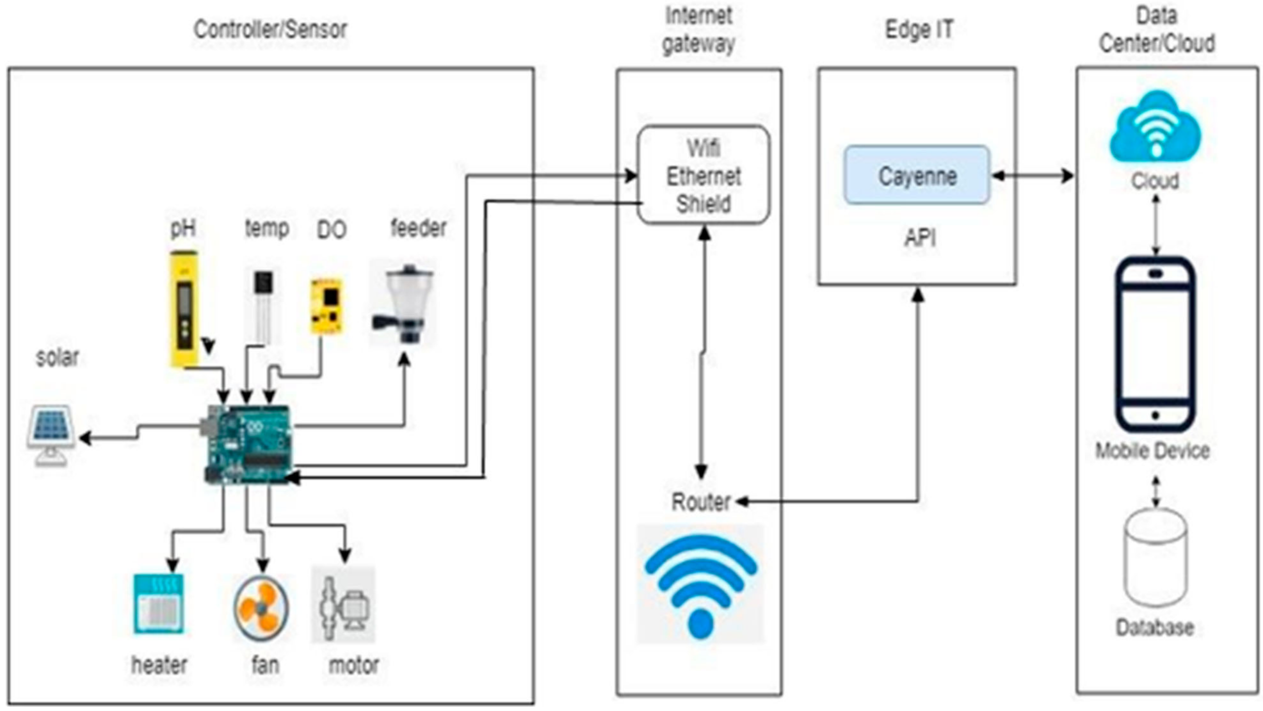

Figure 2. Network diagram [17].

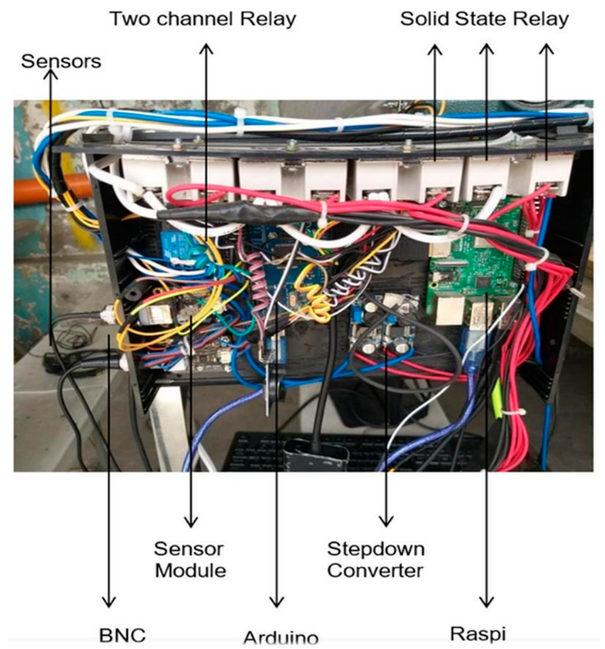

Figure 3. Prototype image.

the negative port was on the ground. Moreover, the Arduino controller is connected to the Raspberry PI. A lithium battery slot was provided to ensure time and date is on and synchronized. A step-down converter's output was connected to the Arduino and raspberry pi while the input port was connected to the battery. Its purpose was to lower down the voltage to 5 V [17].

As for the feeder shown in Figure 5, its ready-made stainless-steel circular design (120 cm × 45 cm × 65 cm) fits on a 300-l aquarium tank. To hold the cylindrical feeder, two pillow blocks placed at both ends served as holder of the feeder. A wiper motor controlled the feeder, and its activation was dependent on the number of motor turns. An infrared sensor-controlled motor turn. Once the wiper motor rotated, at a certain point, a small piece of metal activated the infrared sensor by blocking the pathway; it was counted as one turn in its programme [17].

A peristaltic pump was used to displace liquid solution (neutralize pH levels) from a cylinder to the tank. The inlet hole of the pump was connected to a rubber hose placed in the cylinder, while the outlet hole was connected to a rubber hose going to the aquarium tank. The pump was connected to the Arduino controller [17].

The power source of the prototype was through a solar panel or a direct input. A solar charge controller was provided. Its input was connected to the 50 W solar panel, and output was connected to the 12 V, 20 A. A power cord connects the Arduino to the fully charged battery. As for the direct input as a power source, the power cord was connected to a 12 V 8.3 A power supply. After the hardware assembly, hardware testing was performed to ensure the solar panel was charging, sensors responded to the programme set on the board and other functionalities set are working.

2.2.2. Mobile application

To illustrate the design of the mobile app, Figure 6 is a sample screenshot of the developed android mobile application, which is used to set water parameters, automated feeding, manual controls, etc. Most of low-cost phones in the Philippines are using Android as its operating system. Android is a popular open-source mobile

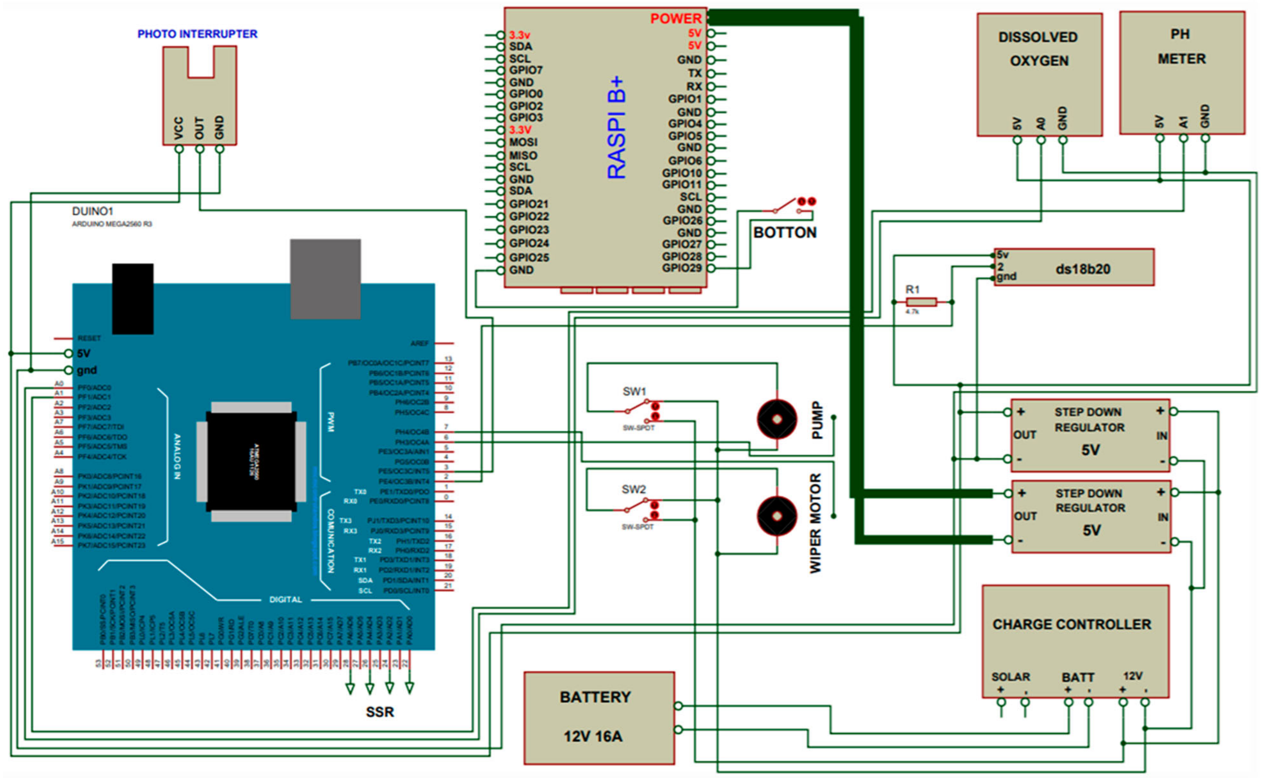

Figure 4. Schematic diagram prototype.

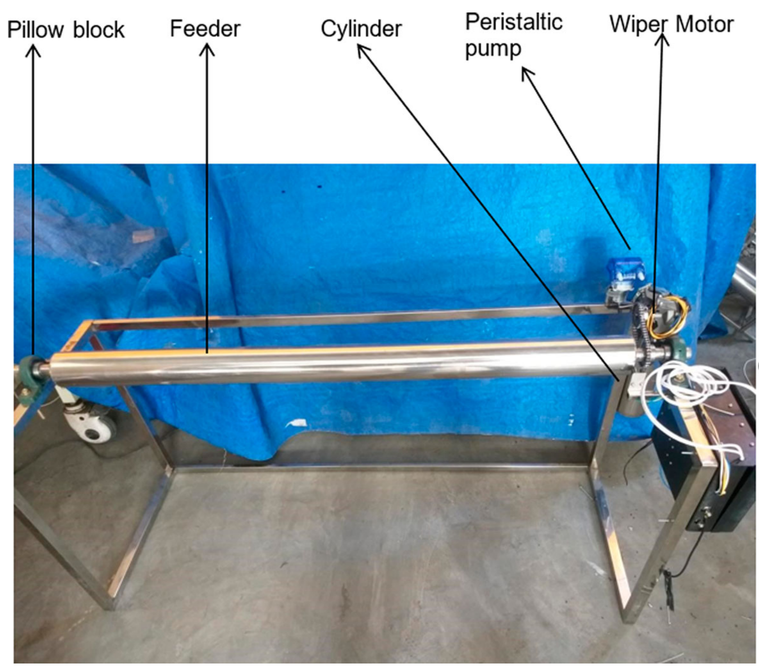

Figure 5. Feeder module.

operating system with a simple app development process. For many young people, Android development is the most wanted and desired job option, and it has exploded in popularity. Other benefits of opting to use Android platform includes customizable interface, ease of installation and simplifies integration facility [20]. These are some of the factors considered in choosing android as the operating system's mobile app in this study.

2.2.2.1. Account profile. This module in the mobile app allows a user account to view their personal profile (see Figure 7). A user of the mobile app can change their password and send message/s which may contain technical issues, suggestions and recommendations to improve the system's service further. The administrator account can create a profile for the user account. Notification of the user profile created is sent via email.

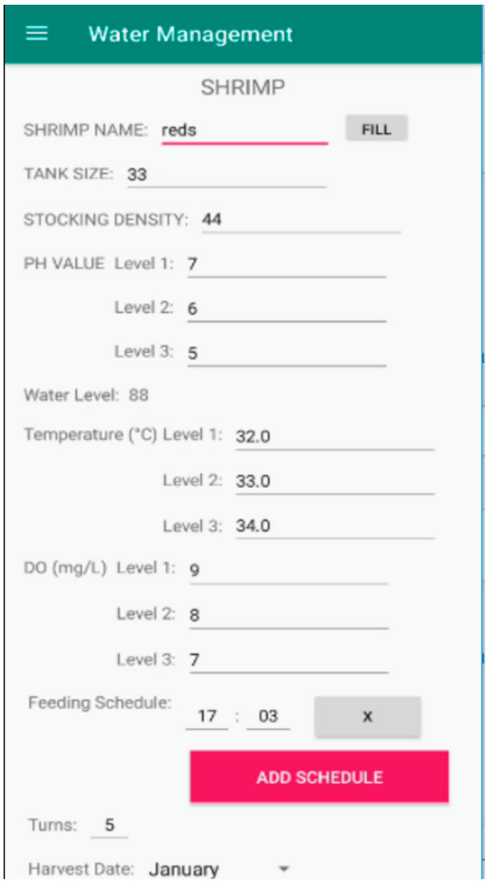

Figure 6. Mobile app screenshot.

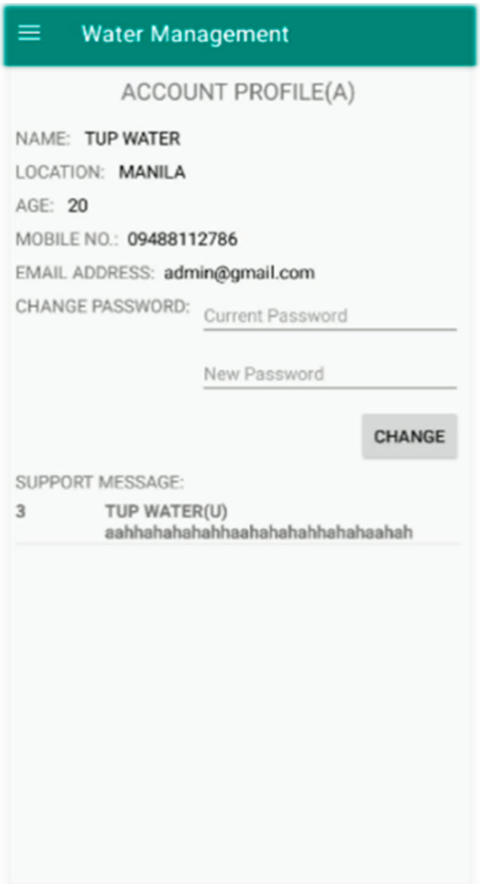

Figure 7. Account profile.

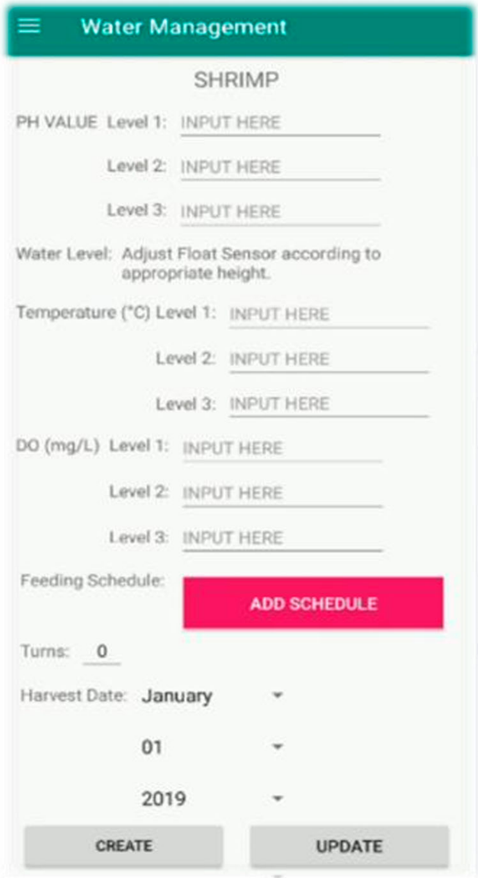

Figure 8. Fish/shrimp profile module.

2.2.2.2. Fish/shrimp profile module. The admin account can add and update water quality parameters (pH, DO and temp.) and the water level to a fish/shrimp profile in the module. The design of the mobile app in setting alert values can be customized allowing the user to use the prototype in any fish/shrimp specie considering water parameters vary from each of the fish/shrimp specie. With this design, the prototype has the intention to be practical in use for other species. Its dashboard has a fish/shrimp profile where acceptable levels of DO, temp. and pH for each of different species can be set, stored to the cloud database and the fish farmer user has a dropdown in its interface where these set fish/shrimp profiles are visible. Moreover, the automated feeding has a set no. of turns. With this functionality in the feeding system, the end-user can adjust the no. of feeds. This feature somehow makes the system design flexible according to the different fish or shrimp species being cultured, particularly in a biofloc production system (see Figure 8).

Moreover, feeding schedule can also be configured in this module. The user shall set number of motor turns for the feeding. End-user should manually observe the number of feeds (in grams) the feeding motor releases as per the number of turns. Suggested harvest date is also set in the mobile app.

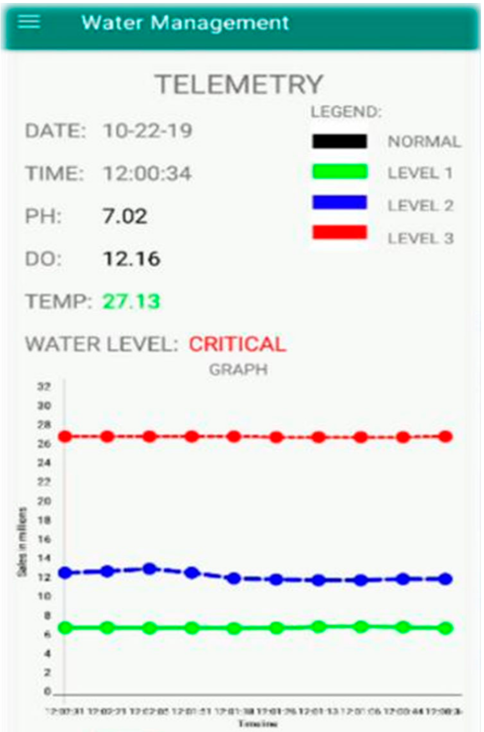

Figure 9. Telemetry module.

2.2.2.3. Telemetry. As shown in Figure 9, the user shall be able to view the current sensor readings of pH, DO and temp. Sensor reading update is set every 13 s. The 13 s interval set was based on the previous IoT studies entitled "ImHome: An IoT for Smart Home Appliances", where the temperature sensor and other sensors used were set at a 13 s interval [21]. To provide better visualization, a graph that maps the sensor value to its corresponding date was displayed. Colour distinctions used for different alert levels are green for level 1, blue for level 2 and red for level 3.

2.2.2.4. Manual control module. In this mobile app module (see Figure 10), the user can manually control feeding, cooling fan, aquarium heater, motor (for DO) and pump. Once the user clicks the 'to manual button, system shall bypass automatic operation, indicating auto-correction is deactivated.

Under the manual operation tab, a user can turn on or off the feeding, motor (DO) fan, heater and pump. The green button indicates the relay is activated and the status is "ON" while a red button means the relay is deactivated and its status is "OFF".

2.3. Testing phase

Once this current build iteration has been coded and implemented, unit tests and performance tests were conducted in this study. The unit test, which is a level of software testing where individual units/components are tested [22], ensures all functionalities set are assessed and met. On the other hand, the performance test, which evaluated the speed, response time and resource usage of a software programme under their expected workload [23], was also conducted.

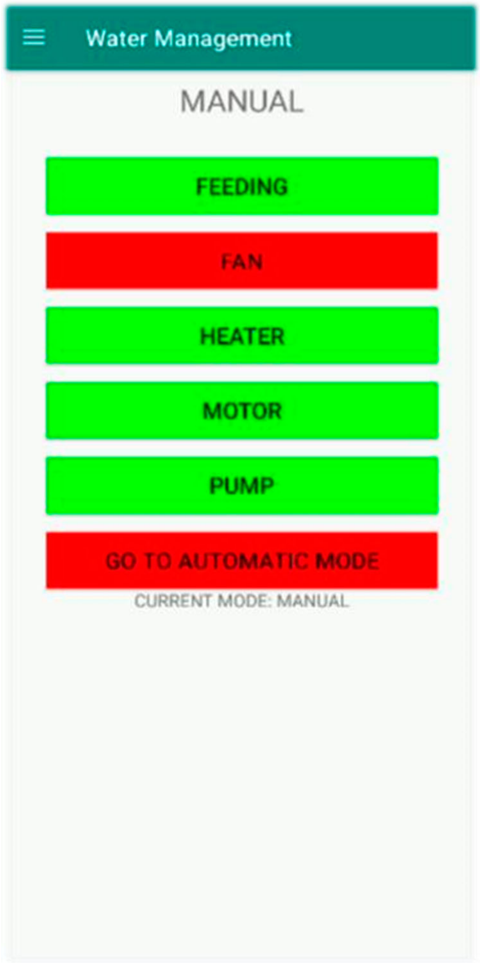

Figure 10. Manual control module.

2.3.1. Unit test results

In this study, an iterative phase-by-phase approach was implemented, where testing was conducted for each stage. During the first iteration, several challenges were encountered. These included loose connections, damaged parts like relays or sensor ports, sensor calibration issues and wrong port connections. In the second iteration, the said problems and the expected functions went well. On the second phase, a programme for the raspberry pi, database and mobile app was developed.

In the raspberry pi programme, it included significant functions such as:

(a) reading sensor inputs (dissolved oxygen, temperature and pH)
(b) log sensor values and auto manage indicator in excel format
(c) interacting with the mobile app
(d) sending sensor values to the mobile app

Table 1. Performance test result.

Device	Connection	Test no.	Page	Average CPU usage	Memory usage	Response time (s)
Samsung Galaxy A6+ Android 8.0 (Oreo) 4GB RAM	Globe LTE - Long Term Evolution (mobile data)	1	Account profile	66%	72.00%	3.9
		2	Shrimp	67%	72.00%	8.2
		3	Telemetry	68%	71.00%	5.7
		4	Manual	65%	71.00%	3.5
Samsung Galaxy A6+ Android 8.0 (Oreo) 4GB RAM	Globe LTE (pocket Wi-Fi)	5	Account profile	65%	72.00%	2.2
		6	Shrimp	67%	72.00%	8.9
		7	Telemetry	68%	71.00%	5.9
		8	Manual	65%	71.00%	2.6
Samsung Galaxy A8 (2016) Android 6.0.1 (Marshmallow) 3GB RAM	Globe LTE (mobile data)	9	Account profile	64%	72.00%	3.9
		10	Shrimp	63%	72.00%	7.2
		11	Telemetry	64%	71.00%	6.2
		12	Manual	61%	71.00%	3.8
Samsung Galaxy A8 (2016) Android 6.0.1 (Marshmallow) 3GB RAM	Globe LTE (pocket Wi-Fi)	13	Account profile	65%	70.00%	2.9
		14	Shrimp	64%	69.00%	8.1
		15	Telemetry	62%	72.00%	6.5
		16	Manual	66%	71.00%	3.2
Samsung Galaxy NOTE 8 Android 7.1.1 6GB RAM	Globe LTE (mobile data)	17	Account profile	62%	72.00%	3.3
		18	Shrimp	62%	72.00%	8.5
		19	Telemetry	63%	71.00%	7.5
		20	Manual	61%	71.00%	3.6
Samsung Galaxy NOTE 8 Android 7.1.1 6GB RAM	Globe LTE (pocket Wi-Fi)	21	Account profile	61%	72.00%	3
		22	Shrimp	63%	71.00%	9.1
		23	Telemetry	61%	69.00%	8.3
		24	Manual	62%	70.00%	3.3

The mobile app primary function included shrimp profile (set sensor values), telemetry and feeding schedule. In the shrimp profile, the user inputs the alert level values for pH, dissolved oxygen, and temperature. In addition, the water level was included in the system. Auto-feeding schedule can also be set through the mobile app. The user can manually control the mobile app's feeder, pump, motor, fan and heater. This is expected once a manual button is pressed; it will activate the corresponding relay and turn on the device connected to that relay.

During the initial stage, a couple of errors were encountered, such errors included

(a) input validation is missing
(b) update of records (sensor values to be set) is not working
(c) inputs do not sync with the database
(d) IP address changes every time the Wi-Fi router restarts
(e) Wi-Fi hotspot do not work
(f) automatic feeding does not work
(g) automatic controls on the motor once the dissolved oxygen reading is below level 3
(h) did not observe error handling

Most errors were fixed at the second iteration of the software development. Detailed unit test results conducted showed that a 100% success rate of the system functionality was achieved on the third iteration/phase.

2.3.2. Performance test results

Presented in Table 1 are the recorded CPU and memory usage, and response time (seconds) in three mobile device platforms. The performance test in the mobile android app was conducted using three media, namely: Samsung A6+, Samsung A8 and Samsung Note 8. The performance assessment tool was done through a third-party app named Resource monitor for the memory usage and CPU temp, and CPU monitor for the CPU usage. Considering all pages in the mobile app and connection type, average CPU usage varies from a minimum of 61% to a maximum of 68%. Memory consumption plays at 69–72%. After measuring CPU usage and memory consumption, trials to measure response loading time were conducted in this test.

In the response time, cache memory was cleared and ensured that the mobile app is the only active application. Observing the response time using a stopwatch, load test results showed that the fastest observed response time for those loading pages is at 2.2 s while the slowest response time is at 9.1 s.

2.4. Experimental research execution

After the conducted software testing was validated, all requirements in the system were functioning and acceptable; experimental research was conducted using a two-group experimental design model. Two groups in this model were experimental group and control group. Data from an experimental group were compared with data from a control group. The experimental group was biofloc tank while the control group was the RAS tank. This control group was separated from the experimental group and had no influence on the experimental results but served as a point of reference on the experiment's outcome. The research question, hypothesis and critical variables are listed below:

2.4.1. Research question

What effect does the integrated automated water management system have on biofloc production in terms of a species' survival and growth rate (white shrimp)?

2.4.2. Research hypothesis

Adapting an integrated water management system into a biofloc production system improves water quality, contributing to the increase of mortality and growth rate of a species.

2.4.3. Experimental procedure

To answer the research question and prove the generated hypothesis of this study, two tanks, T1 and T2 cultured *Litopenaeus vannamei* in 30 days, have undergone procedures stated below. The biofloc managed tank T1 (experimental group) with an automated water management system while Tank T2 (controlled group) was on the RAS method of fish farming. Step by step activity in the experiment conducted is discussed below.

2.4.3.1. Biofloc preparation. Presented in Figure 11 is the actual setup of tank T1 (biofloc tank) and T2 (RAS tank). Two containers, T1 and T2 glass tanks (dimensions: 120 cm × 45 cm × 65 cm), were filled with different stocking densities of fresh tap water – 100, 200 and 300 L. A 30 (+/−5) day old *Litopenaeus vannamei* (white shrimp) was used in the experiment. To undergo dechlorination process, the tank was aerated continuously within the 24-h period using a submersible pump. To introduce inoculum in the biofloc tank, a proportional amount of water with bacterial floc from an outdoor fishpond was added. Tanks were treated with light (12 h of sunlight). To induce biofloc, 10 g of molasses containing 30% of carbon was added daily in 2–3 weeks period until the total suspended solids (TSS) reached a level of 500 mg/L. Once there is biofloc formation, white shrimps were stocked on T1 and T2 tanks, respectively.

Litopenaeus vannamei's stocking density on both tanks was (a) 40 for the 100 L, (b) 100 for the 200 L and (c) 200 for the 300 L. Both tanks have a submersible pump which serves as an aerator. These submersible pumps were connected to a filter box that removed excess food, decaying organic matter and other particulates in both tanks. Right after the biofloc formation in tank T1, the prototype was positioned on tank T1 and started the automated water management and auto-feeding. One-inch tip of the sensors (DO, temperature and pH) were submerged in the water. Other peripherals such as aquarium heater, cooling fan, bubble generator and pump hose were placed as well. The prototype placement in the biofloc tank, T1, is shown in Figure 12.

2.4.3.2. System design. Figure 13 shows the system diagram of the prototype. Automated water management was performed by the prototype developed. Once the prototype detects a decrease (based on the value set by the user) in temperature, the heater is activated. Once there is an increase (based on the value set by the user) in temperature, a fan is activated. The acid base agent is to be added in the biofloc tank to keep the pH level acceptable. Dissolved oxygen is to be maintained at 4–8 mg/L level. Once the dissolved oxygen value is lower than 4 mg/L, the corresponding relay shall activate a bubble generator. To monitor excess TSS in the biofloc process, an Imhoff cone shall be filled with 1 L of water from tank T1. Twenty-four hour is set for the waiting period to settle suspended solids at the bottom. TSS in biofloc is maintained at 500 mg/L [24].

Throughout the whole duration of the experiment for the three different stocking densities, alert levels were set in the prototype as

(a) level 1: pH = 6, DO = 5, temp = 25.5
(b) level 2: pH = 5, DO = 4, temp = 26
(c) level 3: pH = 4, DO = 3, temp = 28

Recommended water parameters are set in other studies (see Table 4); however, this study targets to contribute that if water parameters are at a lower value, still the growth and mortality rate would be highly acceptable. As consulted to an aqua culturist in the Bureau of Fisheries and Aquatic Resources, water parameters set in Table 4 are ideal; however, if water parameters are within the close range, the value will still be acceptable. Sensor readings are logged as an excel file in the raspberry pi platform. On the other hand, readings of pH, DO and temp. in tank T2 (RAS) are manually recorded twice a week.

To manage substances such as ammonia, odours and suspended solids which build up in the water over time due to uneaten food, fish wastes and other organic material, both tanks have an installed filter box, containing an ammonia reduction sponge pad, connected to the submersible pump. Moreover, 70% of water in tank T2 (RAS) is replaced every other day. The percent water replacement was based on the interview results conducted to fish farmers who uses RAS in culturing fish and shrimps.

Moreover, managing TSS and maintaining biofloc formation in the biofloc tank is manually observed. TSS (maintained at 400 mg/L) were measured using an Imhoff cone to attain this requirement. Once a week, 1 L from the bottom part of water in tank T1 was placed in the Imhoff cone. Suspended solids are settled within

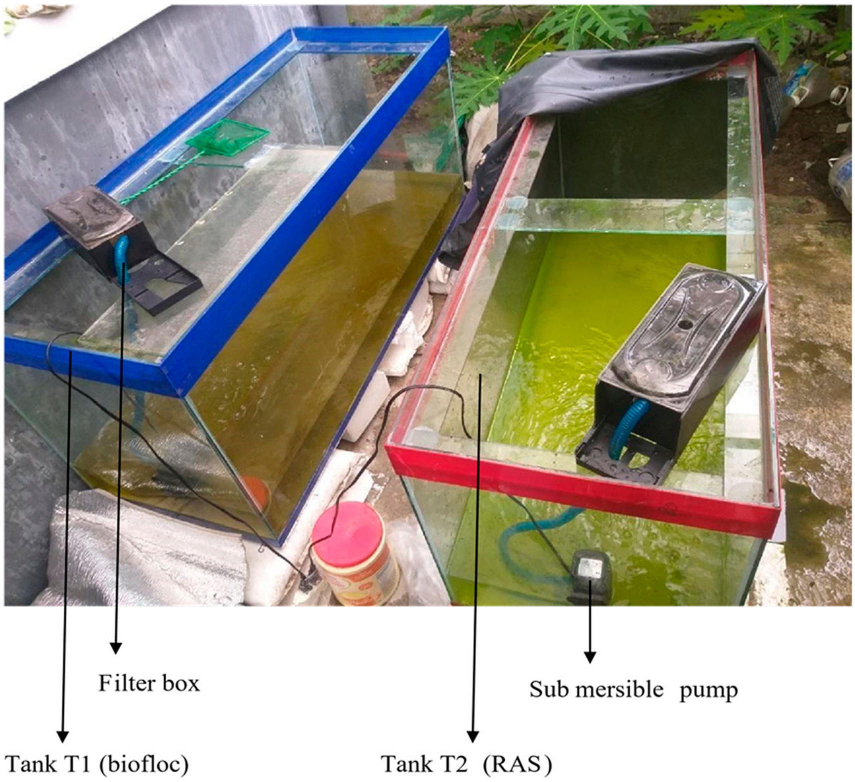

Figure 11. Experimental setup.

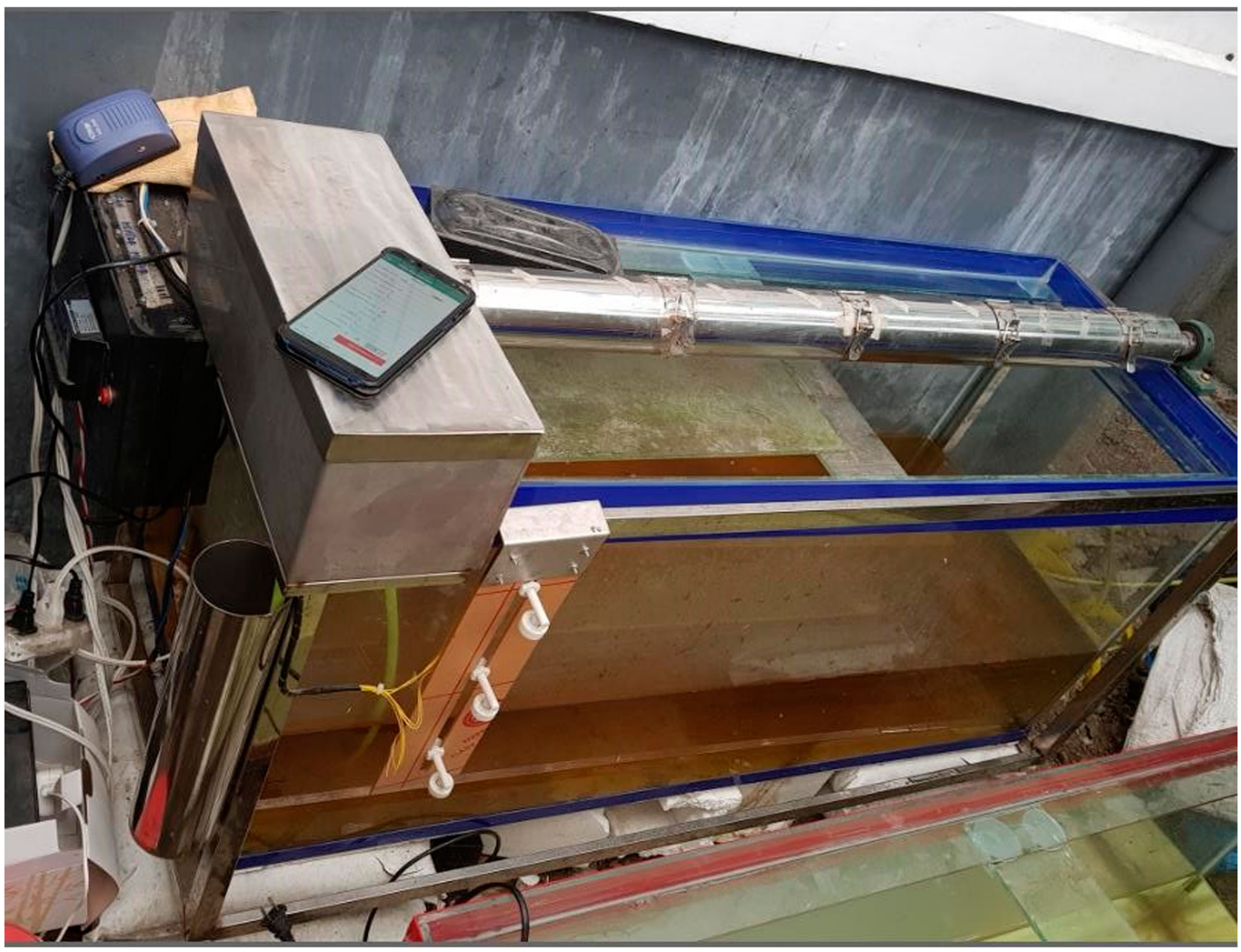

Figure 12. Prototype setup.

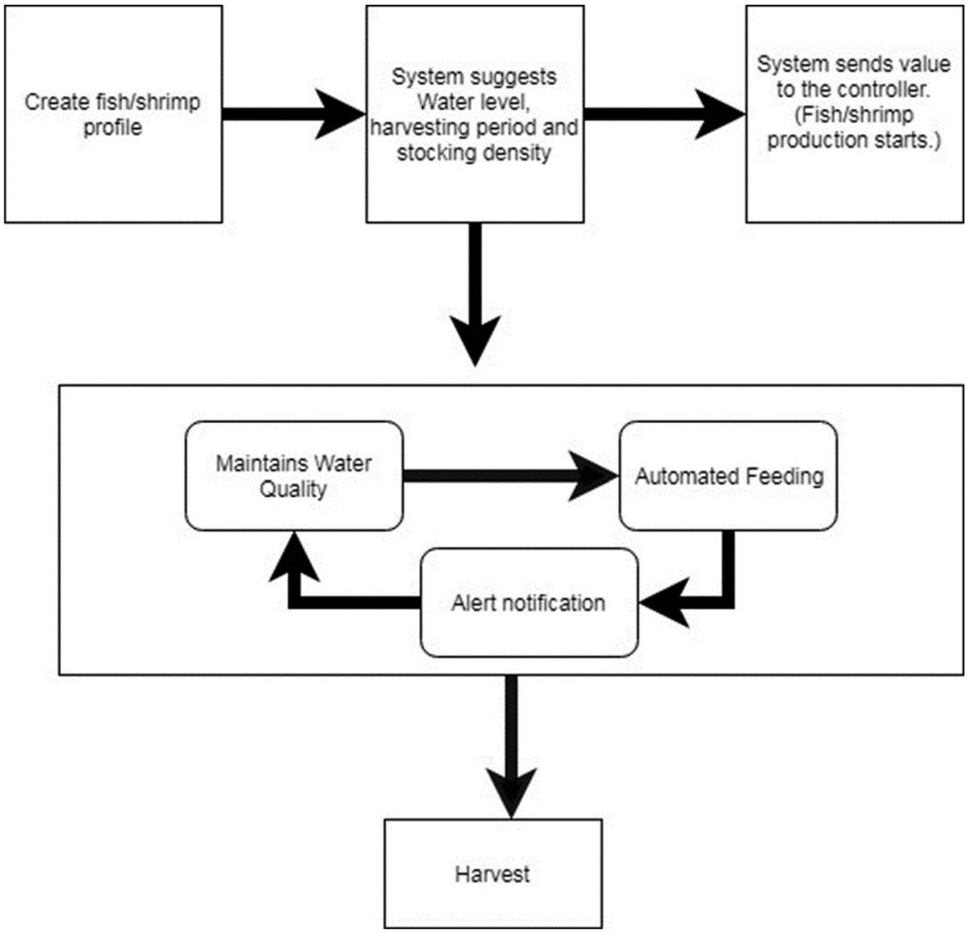

Figure 13. System diagram.

24 h. After 24 h, suspended solids in the bottom of the Imhoff cone are measured. If the mark exceeds 400 mg, clarifier process (clean the filter box and remove few settled solids at the bottom) was observed and repeat the process of measuring the TSS. TSS removal helps eliminate alkalinity and nitrate from the environment. By eliminating solids from the environment, nitrate levels may be minimized. On the other hand, since alkalinity helps keep pH above 7.0, a fast check of pH and additions of sodium bicarbonate are a mean to correct the pH levels [14], and in effect maintain alkalinity levels in its normal state as well.

2.4.3.3. Feeding rate. Table 2 serves as a reference guide for both tanks' feeding weights. Biofloc serves as a food source for the shrimp species; this minimum amount of suggested feed shall be given to the biofloc tank and the maximum amount of suggested feed shall be applied to the RAS. The average weight of a group of shrimps shall be measured weekly. Weight gain shall be reflected on the increase of feed. Feeds shall be given once a day. Tank 2 (RAS) is manually fed, while tank T1 (biofloc) is automated.

The main factor of feeding management is the shrimp weight (measured at the end of each week) observed in the study. The feeding rate used in this study was based on the recommended feeding rate for shrimp based on body weight (see Table 3).

Table 2. Recommended feeding rate for shrimp based on body weight.

Shrimp live body weight (g)	Recommended feeding rate (% body weight/day)
2–3	8.0–7.0
3–5	7.0–5.5
5–10	5.5–4.5
10–15	4.5–3.8
15–20	3.8–3.2
20–25	3.2–2.9
25–30	2.9–2.5
30–35	2.5–2.3
35–40	2.3–2.1

2.4.3.4. Water management process. Presented in Table 4 are the acceptable water parameters in a biofloc production system. Such data will serve as references for the acceptable sensor values to be set in the proposed prototype.

Table 4 depicts the suggested scheduled frequency of measuring the water quality parameters manually in an aquaculture system. Water parameters (temperature, DO and pH) on both tanks were monitored periodically on tank T2 and continuously on tank T1. Temperature and oxygen levels are gauged twice a day, while pH measurements will be once a day [25].

Table 3. Feeding rate.

		Feed weight (g)	
Stocking density	Period	Biofloc	RAS
100 L (40 shrimps)	Day 0	0.3	0.5
	Day 7	0.4	0.6
	Day 14	0.6	0.7
	Day 21	0.7	0.8
	Day 28	0.8	1.2
200 L (100 shrimps)	Day 0	0.8	1.3
	Day 7	1.2	1.5
	Day 14	1.4	1.6
	Day 21	1.9	2.1
	Day 28	2.1	2.9
300 L (200 shrimps)	Day 0	1.6	2.4
	Day 7	2.7	2.8
	Day 14	2.9	3.7
	Day 21	3.2	4.2
	Day 28	4.2	5.4

Table 4. Water quality parameter [24].

Parameter	Ideal amount	Recommendation
Temperature	26–28°C	Lower temp. has slower growth; too high temp. cause stress
Oxygen	5 mg/L	5 mg/L to saturation reduce stress on individuals
pH	6–7.5	Preferably above 7.0 tied to alkalinity

2.4.3.5. Dependent variable measurement (growth and mortality performance). Using the formulas below, survival and growth rates were measured and assessed at the end of each week. Shrimp growth rate formula was based on the method used by Karim [26]. On the other hand, the shrimp survival rate was derived from the study by Luo et al. [27].

Growth rate (% body weight) shall be measured weekly using formula no. 1. In formula no. 1, the difference of the natural logarithm's initial weight and the natural logarithm's weight per day was divided by the number of cultured days and multiplied by 100 to obtain the specific growth rate of the shrimps.

$$\text{Specific growth rate(\% body weight day)} = \frac{(\ln W_t - \ln W_o)}{t} \times 100, \quad (1)$$

where W_t is the initial weight, W_o is the weight at day and t is the culture period (days).

Survival (%) shall be measured at the end of the 30-day rearing period using formula no. 2. In formula no. 2, the difference between the number of dead shrimps and the initial number of shrimps was divided by the initial number of shrimps multiplied by 100 to obtain the shrimps' survival rate.

$$\text{Survival(\%)} = \frac{(N_o - N_t)}{N_o} \times 100, \quad (2)$$

where N_o is the initial number of shrimps and N_t is the no. of dead shrimp.

2.4.3.6. Statistical analysis. To assess significant contribution of the automated water management system vs. the manual way of managing water quality, data recorded on the sensors (tank T1) and on tank T2 every week were mapped on the yield and growth of the shrimp, and results have undergone statistical treatment (t-test).

For the main response variables, that is, the shrimp growth and survival rate, significance tests are done for comparing the difference between two means (t-test).

For the secondary response variables, that is, temperature, dissolved oxygen and pH level, paired samples t-tests were used to determine whether there are significant differences between the two methods. The measurements of these variables were taken simultaneously every day for the duration of the experiment. This means, for each variable, there will be a "pair" of observations per week, one from the manual tank and the other from the automatic tank.

3. Results and discussion

Once a week, the accumulated dead shrimps were recorded in both tanks and in all stocking densities. To measure the increase of stocked shrimp's growth (in grams), the weight of a small container with water from tanks was measured using a digital weighing scale. Subsequently, 30 randomly selected shrimps were placed in a small container, and their weight was recorded. The researcher used a non-probability sampling method. Shrimp samples were chosen based on who is the most accessible during the process where growth rates were assessed. To measure the increase in growth of those 30 shrimps, the difference of the recorded weight with shrimps and recorded weight without shrimp of the small container was computed.

Using formula nos. 1 and 2, survival and growth rates were measured and assessed. The shrimp growth rate formula was based on the method used by Karim [26]. On the other hand, the process for determining the shrimp survival rate was derived on the study by Luo et al. [27]. Recorded results of the computed survival and growth rate are presented below.

3.1. One hundred litres tank

The stocking density for the 100 L tank is 40 post-larvae (PL). By definition, a PL is an immature specie after complete absorption of the yolk sac but before it has attained the appearance of a miniature adult [28]. The research is based on the 40 shrimps stocking density in a 100-l tank using the rule of thumb that is 1 cm specie (fish/shrimp) per 30 cm^2 in a tank. Measured initial biomass for biofloc and RAS are 7.6 and 7.2 g, respectively.

Table 5 depicts the tallied measured weight and growth rate in a 28-day period for the 100 L tank. As presented, the data exhibit a higher growth rate for the biofloc vs. the RAS. Given that there is less food intake

Table 5. Growth rate (100-L tank).

	Measured weight (for 30PL in g)			Growth rate (%)	
	Biofloc	RAS		Biofloc	RAS
Day 0	5.90	6.10			
Day 7	8.20	7.10	Day 7	4.70	2.17
Day 14	10.80	8.30	Day 14	8.64	4.40
Day 21	12.50	9.80	Day 21	10.73	6.77
Day 28	14.70	14.90	Day 28	13.04	12.76

Table 6. Survival rate (100-L tank).

	No. of dead shrimp			Survival rate (%)	
	Biofloc	RAS		Biofloc	RAS
Day 7	1	4	Day 7	97.50	90.00
Day 14	4	4	Day 14	90.00	90.00
Day 21	1	2	Day 21	97.50	95.00
Day 28	0	0	Day 28	100.00	100.00
Total no. of dead shrimp	6	10	Total survival rate	85%	75%

Table 7. Growth rate (200-L tank).

	Measured weight (for 30PL in g)			Growth rate (%)	
	Biofloc	RAS		Biofloc	RAS
Day 0	6.10	6.40			
Day 7	8.80	7.50	Day 7	5.24	2.27
Day 14	10.30	8.00	Day 14	7.48	3.19
Day 21	13.90	10.30	Day 21	11.77	6.80
Day 28	15.60	14.70	Day 28	13.41	11.88

in the biofloc tank, it was expected that the settled solids in the biofloc tank serve as organic food and turn into probiotics, which contribute to the higher shrimp growth rate.

Table 6 presents the quantity of dead shrimps and computed survival rate in a 28-day period for the 100-L tank. Results in Table 6 show a lower no. of dead shrimps for the first three weeks period. Accumulated results show a higher survival rate on the biofloc tank vs. the RAS tank. With the aid of the prototype in managing the water quality, growth rate and survival rate were higher in the biofloc tank.

3.2. *Two hundred litres tank*

The stocking density for the 200-L tank is 100 shrimps. As for the second trial, the water level in the tank was increased to 200-L. In effect, the biomass was increased as well. Measured initial biomass for biofloc and RAS are 19.5 and 21.9 g, respectively.

Table 7 presents the tallied measured weight and growth rate in a 28-day period for the 200 L tank. Comparable to the 100 L experiment trial, the growth rate (computation is based on formula no. 1) was higher in the biofloc than in the RAS tank.

Table 8 presents the quantity of dead shrimps and computed survival rate in a 28-day period for the 200 L tank. Comparing the survival rate of the 100-L to the 200-L tank, the latter was relatively higher. As observed

Table 8. Survival rate (200-L tank).

	Measured weight (for 30PL in g)			Growth rate (%)	
	Biofloc	RAS		Biofloc	RAS
Day 0	6.10	6.40			
Day 7	8.80	7.50	Day 7	5.24	2.27
Day 14	10.30	8.00	Day 14	7.48	3.19
Day 21	13.90	10.30	Day 21	11.77	6.80
Day 28	15.60	14.70	Day 28	13.41	11.88

Table 9. Growth rate (300-L tank).

	Measured weight (for 30 shrimps in g)			Growth rate (%)	
	Biofloc	RAS		Biofloc	RAS
Day 0	5.90	6.10			
Day 7	10.00	7.10	Day 7	7.54	2.17
Day 14	11.00	9.30	Day14	8.90	6.02
Day 21	12.10	10.40	Day 21	10.26	7.62
Day 28	15.60	13.50	Day 28	13.89	11.35

by the researcher, the frequency of the DO level was unacceptable and was low as compared to the 100-L tank trial. This was due to the increased level of water in the tank. The identical result to the 100-L tank, managing the water quality by activating corresponding controls to maintain an expected value of temp, DO and pH into the biofloc tank is a contributing factor to the outcome of the experiment.

3.3. *Three hundred litres tank (stocking density: 200 shrimps)*

The stocking density for the 300-L tank is 200 shrimps. Measured initial biomass for biofloc and RAS are 39.8 and 40.1 g, respectively. Table 9 presents the tallied measured weight and growth rate in a 28-day period for the 300-L tank.

As shown in Table 9, data exhibited a similar trend compared to the 100-L and 200-L trial. The growth rate was relatively higher in a biofloc tank as compared to the RAS. However, comparing the growth rate results in these three trials; it appeared that growth rate has increased. Based on the observation while conducting these experiments, being more familiar with the biofloc process and adjusting the more appropriate levels in the 300-L tank contributes to the increase in the growth rate in this last trial.

Table 10 presents the quantity of dead shrimps and computed survival rate in a 28-day period for the 300-L tank. The survival rate of the biofloc tank vs. the RAS was higher at a 9.5% difference. Furthermore, the survival rate from the 200 L and 300-L tank was closer to the results of the 100 L tank. Factors which lead to the increase of the survival rate under the 200 and 300-L tank includes increasing the water level which in effect produces more oxygen in the water. Moreover, biofloc formation was much established already in the 200 and 300-L tank. Also, for the support of the automated water management to manage the water quality

Table 10. Survival rate (300-L tank).

	No of dead shrimps			Survival rate (%)	
	Biofloc	RAS		Biofloc	RAS
Day 7	8	20	Day 7	96	90
Day 14	2	5	Day 14	99	97.5
Day 21	0	2	Day 21	100	99
Day 28	1	3	Day 28	99.5	98.5
Total no. of dead shrimp	11	30	Total survival rate	95	85

Table 11. Comparison of survival rates of shrimp between biofloc and RAS.

			Paired differences	
Tank	Treatment	Survival rate (%)	% Diff	Sig. (two-tailed)
100-L	Biofloc	85%	10.00%	0.26
	RAS	75%		
200-L	Biofloc	94%	4.00%	0.30
	RAS	90%		
300-L	Biofloc	95%	9.50%	0.00
	RAS	85%		
All tanks	Biofloc	93%	7.90%	0.00
	RAS	85%		

in which under the time where 200 and 300-L trial was conducted, the researcher has applied appropriate alert levels and the feed amount supplied by the automated feeding is close to what is needed by the specie.

3.4. Statistical analyses results

The result is based on the recorded survival and growth rate for all stocking densities. Paired differences were processed using two-tailed t-tests. As shown in Table 11, the percent difference of the survival rate between the biofloc and RAS (Recirculating Aquaculture System) for all stocking densities (100, 200 and 300 L) were obtained. To identify the relationship between the categorical variables, namely the no. of dead shrimps in the biofloc and RAS tanks, chi-square test was used. Results obtained on those three trials (100 L, 200 L and 300 L) were cross tabulated, and using the SPSS (Statistical Product and Service Solutions). tool and the level of significance were determined. Considering the tank size for the survival rate, there are no significant differences detected between biofloc and RAS, in terms of survival rates in the smaller tanks. However, if we look at the more prominent (300-L) tank and overall (combining all tanks), biofloc has a significantly higher survival rate as compared to RAS by almost 10% and 8%, respectively.

Based on the results gathered in Tables 5, 7 and 9, the growth rate mean value of different stocking densities was obtained (see Table 12). Standard deviation and standard errors were received as well. To determine the significant difference of the growth rate results in biofloc vs. RAS at 5% level of significance, two-tailed t-test was used. The growth rates of shrimp are significantly higher in days 14 and 21. However, on the 7th and 28th days, the shrimp in the biofloc tank grew more by 3.6–3.9% (on the average) compared to that of the RAS tank. Generally, the growth rates of the shrimps in the biofloc tank grew significantly bigger – about 3.2% more than in the RAS tank.

Temperature is highly influenced by aquatic animals; aquaculture operations must be timed to match water temperature, and measurements of temperature are important for efficient operations. The growth and survival of shrimps, fish and other aquaculture species are particularly important since they are cold-blooded [29]. Most aquatic animals require oxygen to live. Low dissolved oxygen levels in water indicate contamination and are a key element in judging water quality

Table 12. Comparison of growth rates of shrimp between biofloc and RAS.

		Growth rate		Paired differences		
Day	Treatment	Mean	Std. dev.	Mean diff. (Biofloc–RAS)	Std. error	Sig. (two-tailed)
7	Biofloc	5.83	1.51	3.62	0.88	0.05
	RAS	2.2	0.06			
14	Biofloc	8.34	0.75	3.8	0.46	0.02
	RAS	4.54	1.42			
21	Biofloc	10.92	0.77	3.85	0.67	0.03
	RAS	7.06	0.48			
28	Biofloc	13.45	0.43	1.45	0.65	0.16
	RAS	12	0.71			
Overall	Biofloc	9.63	3.08	3.18	0.42	0.00
	RAS	6.45	3.86			

Table 13. Biofloc vs. RAS water quality parameter analysis.

		pH		Paired differences		
Tank	Treatment	Mean	Std. dev.	Mean diff. (RAS–Biofloc)	Std. error	Sig. (two-tailed)
100 L	RAS	6.03	0.55	−0.26	0.2	0.24
	Biofloc	6.29	0.18			
200 L	RAS	6.07	0.6	−0.11	0.2	0.59
	Biofloc	6.18	0.13			
300 L	RAS	5.83	0.6	−0.33	0.19	0.12
	Biofloc	6.16	0.19			
		Temp.		Paired differences		
Tank	Treatment	Mean	Std. dev.	Mean Diff. (RAS–biofloc)	Std. error	Sig. (two-tailed)
100 L	RAS	26.41	0.56	−0.48	0.22	0.07
	Biofloc	26.89	0.11			
200 L	RAS	25.97	0.59	−0.4	0.21	0.1
	Biofloc	26.37	0.19			
300 L	RAS	26.72	0.74	0.32	0.27	0.28
	Biofloc	26.4	0.19			
		DO		Paired differences		
Tank	Treatment	Mean	Std. dev.	Mean diff. (RAS–biofloc)	Std. error	Sig. (two-tailed)
100 L	RAS	4.65	0.36	−1.38	0.19	0
	Biofloc	6.03	0.36			
200 L	RAS	4.79	0.42	−0.21	0.16	0.21
	Biofloc	5	0.12			
300 L	RAS	4.75	0.84	−0.23	0.28	0.43
	Biofloc	4.99	0.12			

[30]. These claims are supported in this study, having a favourable survival and growth rate result to the biofloc tank where the temperature, dissolved oxygen and pH level are well managed.

Presented in Table 13 are the statistical results in comparing the measured water quality parameters: pH, DO and temp. throughout the three months (100 L, 200 L and 300 L) trial duration. Based on the outcomes of the *t*-test (see Table 13) conducted to assess the level of significance on the measured water parameters in both tanks – biofloc and RAS, it only shows that the 100 L tank trial exhibited a significant difference for the DO level.

Even though there is a zero-water exchange in the biofloc production system, which in its natural progression greatly deteriorates the water quality, the statistical results show that the water quality of the biofloc was in relative value to the RAS tank. The result presented is evident that the automated water management system integrated in the biofloc tank critically contributes to managing the water quality.

4. Conclusion and recommendation

The developed system successfully automated and managed the water quality of the cultured species in a biofloc production system. The 100% success rate result on the unit test indicates that all the functionality requirements set were successfully met. Furthermore, the three-month experimental period conducted in this study (30-day period for each stocking density – 100 L, 200 L and 300 L) has truly evaluated the *Litopenaeus vannamei*'s growth and survival rates of the biofloc vs. the RAS. Based on the statistical results obtained in this study, biofloc had a substantially higher survival rate of almost 10% compared to RAS. In the meantime, the *Litopenaeus vannamei*'s growth rates in the biofloc tank increased significantly – about 3.2% more than in the RAS tank. The results suggest a favourable response to the biofloc with the aid of the automated water management system developed by the researchers of this study.

Considering the stocking rate of biofloc based on the study by [32] Quagrainie (32), an 8000 PL (shrimp) shall be placed in the tank. The rearing period for the white shrimp is 90 days and starts at an initial weight of 3 g per PL. Based on the projected growth rate results of the experimental study conducted and the study of Quagrainie (32), a 15 g final weight is expected at the end of the 90 days cultured period. With the 90% computed mean of the survival rate results in the experimental study conducted, expected harvest is 7200 shrimp with a total weight of 108 kg. At a selling price of P725 pesos per kilo [31], a fish farmer may earn P78,300 pesos (P725 pesos × 108 kg). The automated water management system together with the biofloc setup in an indoor pond expects the cultured period to be continuous. Having a four-harvesting period, a fish farmer may have annual estimated annual earnings of P313,200.00. This computation shows the indoor pond biofloc technology in support of the developed automated water quality management system that is beneficial to the target users.

This study recommends that future researchers explore and conduct assessments on the addition of other water quality parameters such as salinity, nitrite, nitrate and orthophosphate. As this study was created, no other studies presented evidence of a direct sensor for those mentioned water quality parameters. Researchers are encouraged to explore new sensors in the future and provide scientific experiments concerning water quality management.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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