Monitoring System for Shrimp Farming: A Case Study of CAMASIG S.A.

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Abstract. In 2016, Ecuador produced 368,181 tons of shrimp Penaeus vannamei and ex-ported 370,780 tons corresponding to $ 2.58 billion, according to ProEcuador (Institute for Export and Investment Promotion). The shrimp exportation represented 22.76% of the country's non-oil exports. The Ecuadorian shrimp industry invests in technology focused on improving the production of shrimp and the quality of the postlarvae aiming to avoid falls in production, high mortality rates and disparity in the size of shrimp. However, it is necessary that this industry adopts innovative technologies that allow it to improve the quality and production of its products. In this sense, this work presents a case study where a water monitoring system was implemented in a shrimp culture pond of the CAMASIG S.A. company. This system integrates technologies such as Cloud computing, Arduino-based devices, and mobile applications that allow users to remotely monitor a shrimp culture pond, as well as to receive alerts when an out-of-range water parameter (pH, temperature, and dissolved oxygen) is detected. This last module consists of a set of sensors that allows collecting data about the pH, temperature, and dissolved oxygen in the water. This system was evaluated to test its effectiveness in terms of the size, weight, and the percentage of survival of the shrimp achieved when the shrimp culture pond is monitored by this system.

Keywords: Shrimp culture · Monitoring system · Arduino

1 Introduction

In 2016, Ecuador produced 368,181 tons of shrimp Penaeus vannamei [1] and exported 370,780 tons corresponding to $ 2.58 billion, according to ProEcuador (Institute for Export and Investment Promotion). The shrimp exportation represented 22.76% of the country's non-oil exports. In the other hand, in recent years, Ecuador has excelled in the production of postlarvae thanks to the fact that the demand for this product has increased significantly. Therefore, the Ecuadorian shrimp industry invests in technology focused on improving the production of shrimp and the quality of the postlarvae aiming to avoid falls in production, high mortality rates and disparity in the size of shrimp.

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Information and Communication Technology (ICT) provides advantages and new possibilities in different domains. For instance, mobile devices have been incorporated in the medical domain for the monitoring [2, 3] and detection of different diseases [4]. In education domain, the continuous evolution of ICT has allowed students to generate ideas and innovative projects with the aim of improving the quality of life of society as a whole [5]. In entertainment domain, mobile devices such as smartphones and electronic tablets have been adopted thanks to their processing and wireless communication capabilities as well as the integration of sensors such as magnetometers, accelerometers, and gyroscopes, among others [6]. On the other hand, in the food industry, embedded systems and sensors have been used in conjunction to collect and analyze information from the environment in order to improve the production and quality of tilapia fish [7]. In [8], the authors describe a system to monitor the degree of freshness of the tilapia fish. This system uses an optical sensor that changes color in response to the pH alteration, which occurs in the presence of alkaline vapors such as volatile amines (TVB-N) produced during the deterioration of fish. Considering the above discussed, it is necessary that the food industry adopts ICT that allow it to improve the quality and production of different food products. Besides, the adoption of ICT could help to reduce obstacles and uncertainty, optimize resources, add value to food production, as well as encourage the entrepreneurship of professionals.

Shrimp farming in Ecuador is an important activity that has been carried out for 40 years. In fact, Ecuador is considered the pioneer of shrimp farming in America. Ecuador produces 2 types of shrimp, namely: (1) white shrimp or Litopenaeus vannamei, which, due to its high resistance to environmental changes in captivity, represents the 95% of the total production; and (2) shrimp Litopenaeus stylirostris, which represents only 5% of the production. Table 1 shows Ecuador's shrimp exports (percentages) from the January–March 2018 according to the National Aquaculture Chamber. These data show that in America, exports of this product have been maintained, meanwhile, in Asia, there has been an increase of 8% compared to January.

Table 1. Exports (percentages) of Ecuadorian shrimp.

Country	January 2018	January–February 2018	January–March 2018
Africa	0%	0%	0%
America	2%	2%	2%
Asia	51%	54%	59%
USA	19%	17%	16%
Europe	28%	27%	23%

In Ecuador, the cultivation of white shrimp is usually done in ponds, which must comply with the optimal parameters of temperature, pH, and oxygen. These parameters are of great importance since they influence the feeding, growth and optimum development of the shrimp. Currently, there is a great boom in the adoption of ICT by shrimp companies, which makes this industry one of the most dynamic in Ecuador.

This work presents a case study where a water monitoring system was implemented in a shrimp culture pond of the CAMASIG S.A. company. This system integrates technologies such as Cloud computing, Arduino, and mobile applications. Also, it sends messages to the user when detects an out-of-range water parameter. The remainder of this paper is structured as follows: Sect. 2 described a set of research efforts related to the monitoring systems. Then, Sect. 3 details the hardware and software components of the water monitoring system presented in this work, whereas Sect. 4 describes the case study. Section 5 presents the evaluation performed to test the effectiveness of this system in terms of the size, weight and the percentage of survival of the shrimp achieved when the shrimp culture pond is monitored [9] by this system. Finally, Sect. 6 discusses our conclusions.

2 Related Works

The ICT plays a very important role in society and specifically in different sectors of the production industry. In this industry, intelligent automation systems that encompass control and supervision tasks have been implemented. These systems aim to guarantee the expected results in the mining and oil, agricultural, aquaculture and forestry sectors [10]. Mining and foreign-currency generation are some of the activities that contribute the most to the gross domestic product of a country. However, mining workplaces are generally located in areas far from urban centers, which requires a series of logistical, planning and security efforts in order to be efficiently performed. In [11], the authors presented a real-time monitoring system that allows controlling a security dam. In addition, this system allows automatically and remotely obtaining pre-alarm information in order to reduce risks and accidents. In [12], the authors present a sheep monitoring system that aims to protect them from attacks by wolves. For this purpose, this system uses sensors to measure the body temperature and heart rate of the sheep. In this way, when there is a drastic change in these parameters, an alarm is sent to the user to he/she carry out the necessary actions. As can be seen from above, technological advances in the development of monitoring systems allow collecting and processing greater amounts of relevant information of animals and their environment with the aim of improving their production, growth, and health [13].

Monitoring systems are also used in the aquaculture domain. For instance, in [14], the authors presented a real-time fish monitoring system that allows measuring the amount of lactic acid in the fish's blood in order to measure their stress levels. In [15], a monitoring system that combines precision aquaculture with open hardware platforms and Artificial Intelligence is presented. This system automatically registers physicochemical variables of water (dissolved oxygen, temperature and pH), and processes them using fuzzy logic in order to determine the quality of the water. In [16], the authors proposed an automated system for the administration of food in the culture of tilapia fish. This system uses wireless technologies for food administration and a SCADA-type (Supervisory Control And Data Acquisition) program to remotely monitor the status of each food dispatcher. On the other hand, in Machala, Ecuador, a system for measuring the temperature of a pond for the culture of fish was implemented. This system uses a temperature sensor based on the 16F84A PIC controller and provides a LED display that allows the user to view the data captured by the sensor.

In other work, a system for taking water samples is implemented aiming to register and check the quality of water.

Nowadays, mobile applications have been adopted in multiple domains to solve a wide range of problems. However, in Ecuador, there is no a mobile application for shrimp culture that allows monitoring shrimp culture ponds and that provide information on temperature, pH and dissolved oxygen in the water [17]. In this sense, this work presents a water monitoring system that provides an Android-based application that allows users to remotely monitor a shrimp culture pond. Also, this application sends alerts to the users when an out-of-range water parameter is detected by the Arduino-based module. This last module consists of a set of sensors that allows collecting data about the pH, temperature, and dissolved oxygen in the water.

3 Hardware and Software Features

This section describes the hardware and software used for the development of the monitoring system of shrimp culture ponds presented in this work. With respect to hardware platform, this system uses Arduino, an open-source platform for developing electronic prototypes. Arduino allows developing solutions that integrate sensors to obtain various parameters in real time. In this sense, the system presented in this work integrates an Arduino-based solution that allows to measure in real time the temperature, pH, color, proximity, and dissolved oxygen in the water.

Regarding software used in this work, two main development tools were used, namely Android Studio and MySQL. On the one hand, Android Studio is the official integrated development environment (IDE) for the development of Android-based applications. This tool was used to develop the Android-based application that allows users to send commands to the Arduino-based system, as well as visualize the data coming from the sensors integrated into it. On the other hand, we use the MySQL database manager to store the information coming from the sensors. This information is

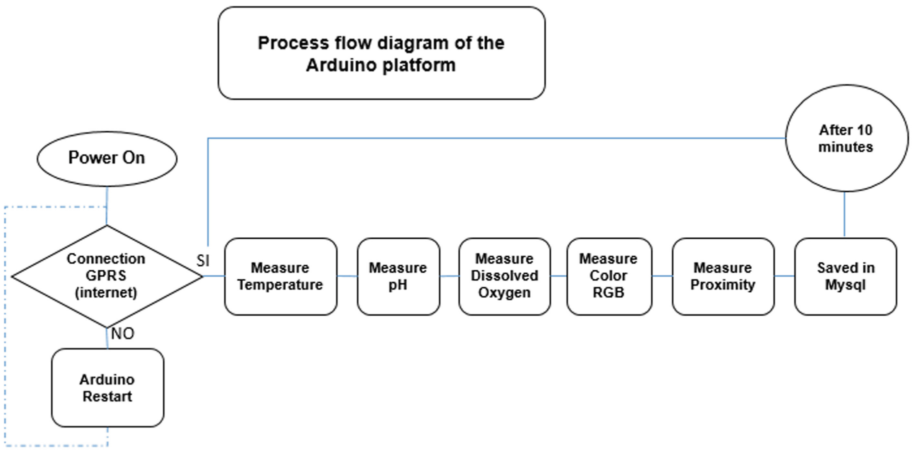

Fig. 1. Flow diagram process.

sent to the MySQL database hosted in the cloud via GPRS devices. The mobile application uses this information to generate alarms when the monitored parameters vary drastically. In addition, this application allows users to view the monitored data and generate reports that support decision making with respect to the tank for shrimp farming.

Figure 1 depicts the flow diagram that describes the monitoring process of the shrimp culture pond. This process goes from obtaining data through sensors to its storage, processing, and transformation into useful information for the end user.

4 Case Study

Despite water monitoring is a relevant task for a successful shrimp culture, the company CAMASIG S.A. does not have technological tools that allow it to obtain data from the pond for shrimp larvae culture, nor to monitor its evolution and maintenance. In addition, this company does not have an application that allows it to store data from water monitoring process to support decisions. This situation generates inconveniences because a simple variation of water parameters might cause diseases in the shrimp and even its death. In order to solve the aforementioned problems, this work presents a water monitoring system based on open source technologies. Specifically, this system offers an Android-based application that allows monitoring the levels of temperature, pH, color, proximity, and dissolved oxygen in the water. Furthermore, this mobile application allows biologists and employees in charge of shrimp culture to control the parameters of the water to which the shrimp are exposed.

4.1 Water Monitoring System Architecture

The water monitoring system described in this work was implemented in a shrimp culture pond of the company CAMASIG S.A. This system integrates Arduino-based technologies to monitor the levels of temperature, pH, color, proximity, and dissolved oxygen in the water. Specifically, the architecture proposed in this paper (see Fig. 2) consists of the three layers described below:

1. Presentation layer. This layer contains the mobile application that allows the user to monitor the water through different forms, as well as receive the corresponding alerts when water parameters vary drastically.
2. Data access layer. This contains the classes that interact with the system database.
3. Devices layer. The devices layer consists of all the electronic devices such as sensors and actuators that allow collecting the parameters of the water to be monitored.

As can be seen in Fig. 2, the architecture of the water monitoring system offers a set of services that support the company business process. In addition, the independence between the layers that compose the architecture enables the continuous evolution of it because this fact allows the addition of new features without affecting basic functionality.

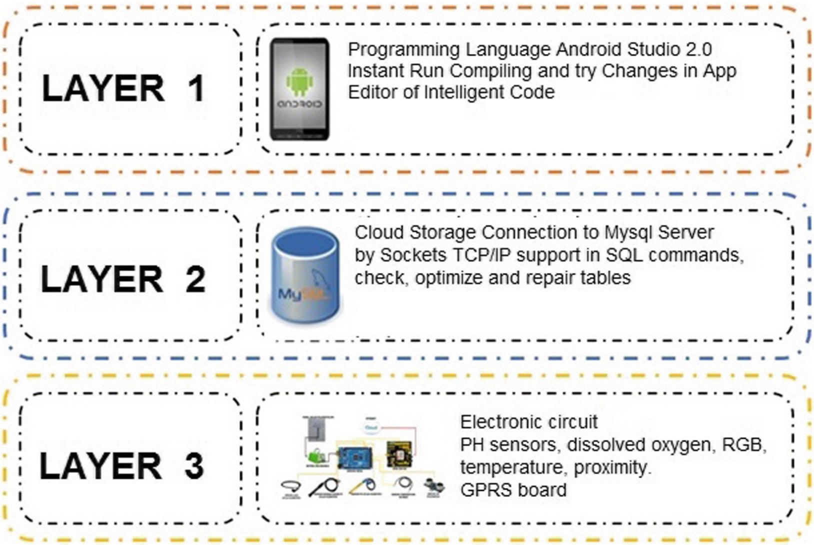

Fig. 2. Monitoring system architecture.

4.2 Morphology of the Monitoring System

As mentioned earlier, the water monitoring system presented in this work provides a module based on Arduino technology that allows collecting all water parameters considered by the system. Specifically, this module uses the hardware described in Table 2. On the other hand, the system was developed by using next software: Android Studio 2.3.3, PHP, MySQL, Java, and Arduino IDE. Finally, it must be mentioned that the database is hosted in the Cloud.

As can be seen in Fig. 3, the Arduino-based module obtains water parameters through the sensors described in Table 2. This data is sent to the MySQL database via Internet. For this purpose, this module uses a GPRS SIM900 studio card and a mobile phone chip. Moreover, the Arduino-based module is powered by a solar panel battery which consists of a 4-m stainless steel bar. This panel is located about 1.5 m from the surface. Meanwhile, the sensors remain submerged in the water.

Figure 4 depicts the data flow between the sensors, the Arduino board, the database, and the mobile application. This data flow is explained below.

First, the sensors obtain the data of temperature, pH, color, proximity and dissolved oxygen in the water of the shrimp culture tank. It is important that the values of these variables are within the ranges established in Table 3 since these variables greatly influence the correct feeding, growth, and development of shrimp.

- The quality of the shrimp depends a lot on the pH of the water. In this sense, the pH sensor indicates how acidic or alkaline water is. On the other hand, the proximity sensor prevents the water level of the tank from reaching the Arduino-based device that contains the sensors. When the water level reaches a distance of less than 10 cm with respect to the device, a motor is driven to maintain the Arduino-based device

Table 2. Hardware used in the monitoring system.

Hardware	Specifications
Arduino Mega 2560	Microcontroller: ATmega2560 Operating voltage: 5 V Input voltage (recommended): 7–12 V Input voltage (limits): 6–20 V Digital I/O pins: 54 (of which 14 provide PWM output) Analog input pins: 16 DC current per I/O pin: 40 mA DC current for 3.3 V pin: 50 mA Flash memory: 256 KB of which 8 KB used by bootloader SRAM: 8 KB EEPROM: 4 KB Clock speed: 16 MHz
GPRS SIM900	Quad-band 850/900/1800/1900 MHz GPRS multi-slot class 10/8 GPRS mobile station class B Transmission power 2 W @850/900 MHz Control via AT commands AT commands for operations with TCP/IP sockets
Sensors	PH sensor, EZO RGB sensor, proximity sensor, temperature sensor, dissolved oxygen sensor
Solar panel and battery	3 solar panels and a double USB Recharge to 2 A Micro USB cable for Android devices

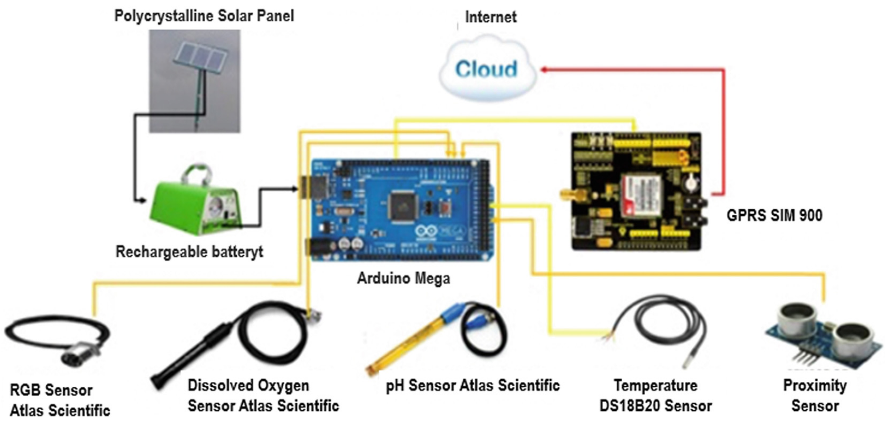

Fig. 3. Monitoring system.

far from the water. Finally, the EZO RGB sensor captures the color of the water. This sensor is capable of recognizing five different colors that determine the characteristics of water. These colors are: Pale green. This color indicates an adequate concentration of algae in the pond.

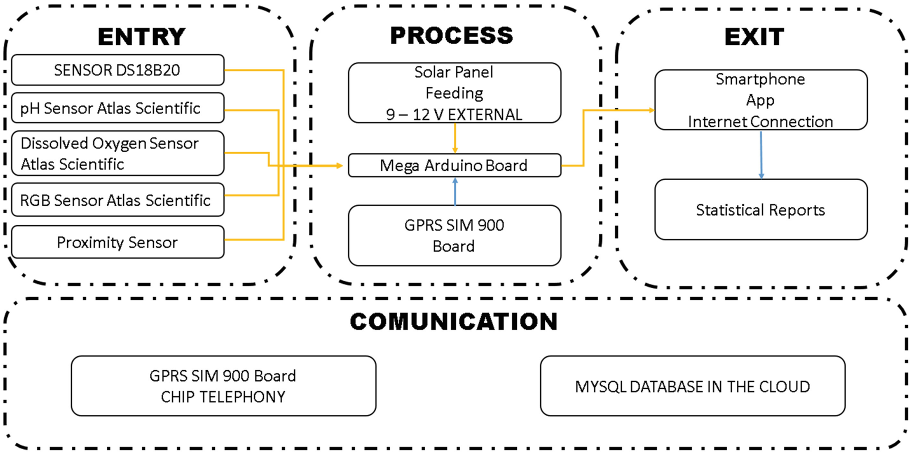

Fig. 4. Data flow of the monitoring system.

Table 3. Parameter settings for shrimp.

Parameter	Value	Scale
Lowest lethal temperature (°C)	14	−50 and 125 (°C)
Optimum temperature (°C)	26–30	−50 and 125 (°C)
Highest lethal temperature (°C)	40	−50 and 125 (°C)
Optimal dissolved oxygen	5–10	2 and 10
Optimal PH	7–9	1–14

- Gray. This color indicates a low concentration of algae in the pond. This situation demands fertilization and changing the pond water.
- Moss green. This color indicates that the algae begin to die. This situation demands to immediately change the pond water.
- Shining green. This color indicates large concentrations of algae. This situation demands to change the pond water to reduce the risk of a decrease in the concentration of oxygen dissolved in the water during the night.
- Brown. This color indicates a large number of dead algae due mainly to the lack of nutrients and excess metabolites. In this case, it is necessary to change the pond water and fertilize the pond.

Figure 5 shows the concentration of pH and dissolved oxygen in the water of a set of samples used in this work. The values 1, 2, and 3 correspond to the colors brown, pale green, and gray respectively. Also, it is observed that when the concentration of oxygen is in an optimum range, the color of the water tends to pale green (2); when there is a low concentration of oxygen, the color of the water tends to brown (1); and, when there is a high concentration of oxygen but not many algae, the color of the water tends to gray (3). Despite these data, it was observed that the color of the water is more related to the turbidity of the water.

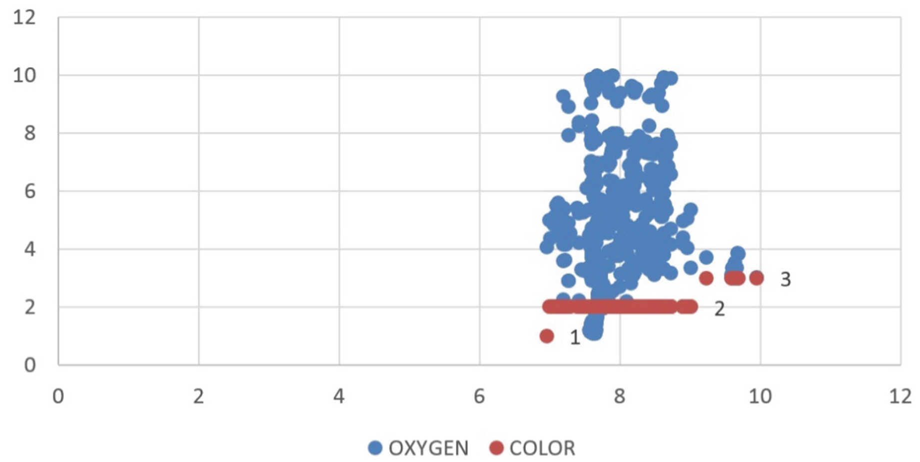

Fig. 5. pH and dissolved oxygen.

The water monitoring system sends email messages to the user when the water parameters are out of range. Figure 6 shows some messages sent by the system. For example, the system sends the messages “The current tank temperature is N” when this parameter is less than 26 or greater than 30; “Oxygen dissolved in water is low” when the value of this parameter is less than 4; and “The pH of the water is N” when this parameter has a value less than 7 or greater than 9.

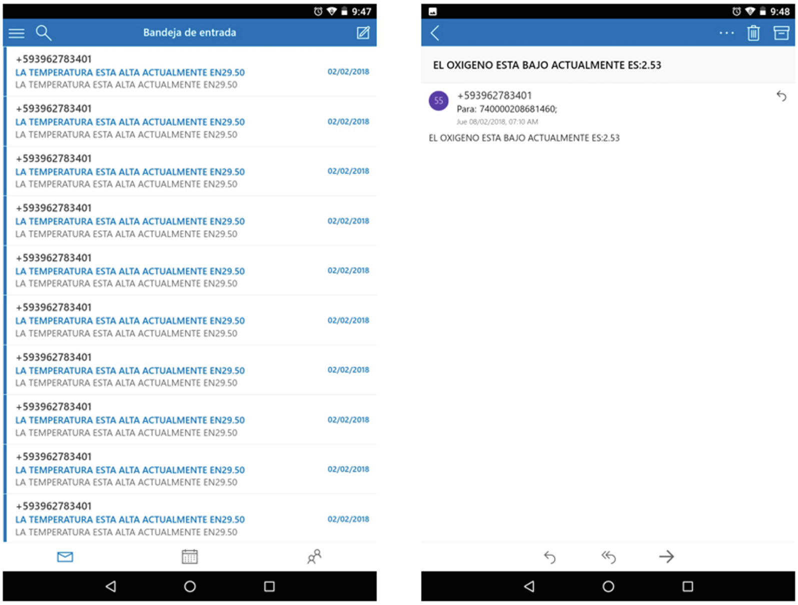

Fig. 6. Monitoring system alerts.

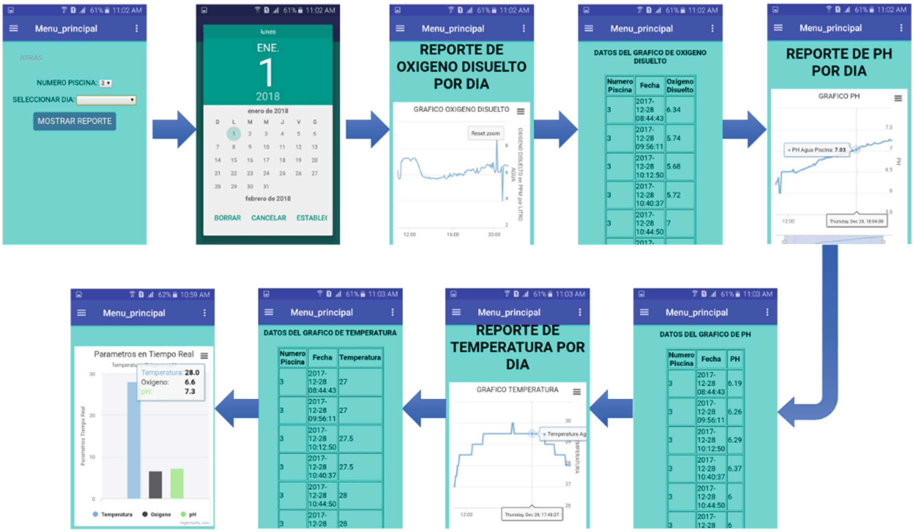

Fig. 7. Reports by day.

Finally, the Android-based mobile application also allows users to generate reports of the different water parameters that are being monitored. Figure 7 shows the mobile interfaces through which the user generates reports by day, week, month, year, as well as a specific period.

4.3 Test Cases

The development process of the water monitoring system presented in this work followed the XP methodology [18]. This methodology is divided into five phases namely: analysis, planning, design, coding, and testing. In addition, this methodology allows performing partial tests with the aim of obtaining a product that meets the needs of the company. Once the water Arduino-based water monitoring system was developed, this was implemented in a shrimp pond of the company CAMASIG S.A. The data collected through this system were stored in a database hosted in the cloud for further analysis.

The water monitoring system presented in this work was used for 120 days by the company. In this period, 3992 samples containing the values of all parameters considered by the system (temperature, pH and dissolved oxygen in the water) were collected. From the collected data set, 480 samples were selected corresponding to the periods from 4:00 to 4:30 and from 16:00 to 16:30. These periods were selected because the shrimp culture pond should be monitored in the morning and in the afternoon to maintain the quality of water in an optimal state [19, 20].

In order to evaluate the effectiveness of the proposed system, the data obtained through this system were compared with those obtained manually by the people in charge of monitoring the pond for shrimp farming. Table 4 presents the average of the results obtained for each of the three parameters considered in this evaluation. As can be seen, there is no great difference between the results obtained through our proposal

Table 4. Average of the results obtained by sensors in the pond 3.

Parameter	Average value manual	Average value of the application
Temperature	27.00	26.63
Dissolved oxygen	7.97	6.5
Average pH	5.12	5.21

and those obtained manually. For instance, the temperature values had a variation of 0.37, the pH had one of 0.09, and the dissolved oxygen had one of 1.47.

4.4 Recommendations

The Arduino-based water monitoring module must be installed in an area where there is a wide mobile network coverage as it uses GPRS technology to send messages or alerts to the user. In addition, this module must be located where the solar panel that composes it can receive direct sunlight so that the battery is always charged during operation. On the other hand, the water monitoring system described in this work can be implemented in any company dedicated to the culture of aquatic species since it allows monitoring the pH, color, temperature and dissolved oxygen in the water, which are the main parameters that should be considered in this domain.

The current version of the monitoring system only considers three water parameters. However, as future work, we are planning to add a salinity sensor and a sensor to measure the turbidity of the water [21]. This will provide more data that support user decisions regarding the quality of water of the shrimp culture pond.

5 Results

Figure 8 shows the number of times that the temperature, pH, and dissolved oxygen values obtained manually and through the application were out of range. As can be seen, the number of times that out-of-range values were obtained by the application is higher than when the data are manually obtained. We ascribe these results to the fact that the sensors used by our proposal allow obtaining more precise values. As can be seen in Fig. 8, there is a big difference between the number of times the system obtained an out-of-range pH value (284) and the number of times that out-of-range pH values were manually obtained (11). Although the difference between the pH values obtained by both methods had an average value of 0.21, our proposal was able to detect more out-of-range pH values and notify the user. The generation of these notifications is very important since a pH value out of range can produce lethal effects in shrimp. With regard to the oxygen parameter, our proposal was able to generate 57 alerts more than the manual method. It should be mentioned that the oxygen parameter varies according to the time of day, being that in the early morning it tends to fall and in the evenings it increases.

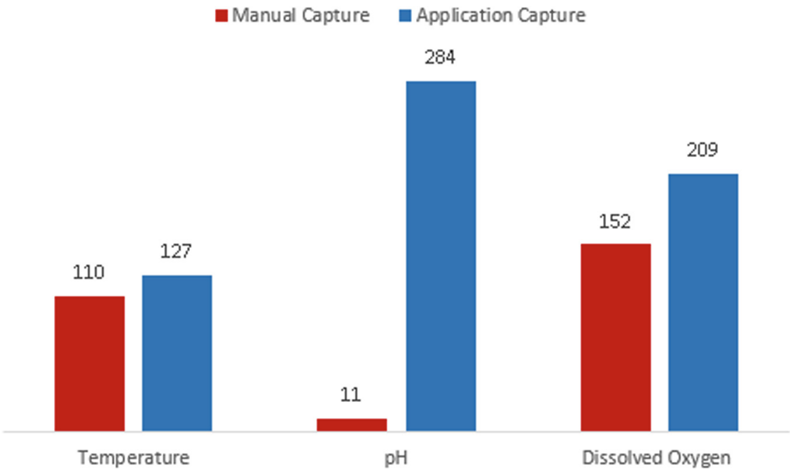

Fig. 8. Alerts obtained manually and through the application.

5.1 Evaluation

The water monitoring system was implemented in the shrimp culture pond number 3 of the CAMASIG company during a complete shrimp farming process (120 days). To evaluate the effectiveness of this system, we compared the length, weight, and percentage of survival of the shrimp cultured in the pond 3, with those cultivated in the pond 2, which was manually monitored. Table 5 presents the results obtained, where it can be seen that the shrimps cultured in pond 3 reached a larger size (9–12 cm) and weight (20 g) than those cultured in the pond 2 (8–10 cm and 17 g, respectively). It is important to mention that the commercial weight of shrimp ranges from 10 to 20 g. This weight is reached between 95 and 120 days after sowing. Hence, our proposal obtained better results for commercial purposes. Finally, the percentage of survival of the shrimp obtained a higher value in the pond where our proposal was implemented.

Table 5. Evaluation metrics used for shrimp farming process.

Metric	Pond 2	Pond 3
Shrimp length (cm)	8–10	9–12
Weight (g)	17	20
% survival	80–90	90

6 Conclusions

This work presents a water monitoring system focused on shrimp culture ponds. The architecture of this system consists of three layers clearly differentiated and independent of each other. This feature will allow adding new features and sensors in order to provide the user with more information that supports their decisions. The most important technologies that are integrated into this system are Cloud computing, Arduino-based devices, and mobile applications. With respect to the mobile application, it allows users to monitor the shrimp culture pond from anywhere. The main benefits that our proposal provides to the shrimp culture process are: (1) the shrimp mortality rate decreases; (2) it can help prevent diseases by alerting the user about out-of-range water parameters; (3) agility, since the real-time monitoring allows users to perform the corresponding actions to deal with risk factors; and (4) innovation, since this system integrates technologies such as mobile devices, GPRS board [22, 23], solar panels [24], and sensors. It is worth mentioning that our proposal is eco-friendly since it uses a solar panel to power the Arduino-based monitoring module. On the other hand, the Cloud computing technology decreases the hardware and software costs necessary for the implementation of this system. This situation, in conjunction with the fact that this system was developed by using open-source hardware and software, makes this system an economical solution for companies dedicated to the culture of aquatic species.

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