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CONTROL OF DISSOLVED OXYGEN IN WATER FOR INTENSIVE TILAPIA CULTURE USING IOT

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ABSTRACT

This article presents the design of a prototype for the monitoring, recording and control of the most representative physicochemical variables in fish farming such as dissolved oxygen, temperature and pH in a tilapia culture. This in order to optimize the living conditions of this fish species and counteract the negative effects such as increased mortality in the production process. For this, the system has a temperature sensor DS18B20, a commercial sensor for pH measurement SEN0161 and a dissolved oxygen detector of the company Atlas Scientific. These will be responsible for obtaining the respective values in real time of each of the physicochemical variables. The system also has a control stage managed by a simple plate computer or commonly known as Raspberry Pi, which fulfills the task of acquiring all the information. The prototype also has a local application developed in Qt Designer whose objective is to act as a graphical interface for the visualization and constant monitoring of the measurements made by each of the sensors. Also it has a server that stores and organizes remotely on a page web all the information obtained so that the user has easy access and can monitor in real time the tanks with tilapia.

Keywords: fish farming, IoT, pH, physicochemical variables, temperature, web service.

1. INTRODUCTION

Fish production is a very profitable industry. In this sector the reproduction and breeding of various fish is encouraged and among these is the red tilapia, which due to its feeding habits, adaptability, wide tolerance, rapid growth, easy reproduction, resistance to diseases and the possibility of supporting adverse conditions in culture, it is ideal for the production in ponds under extensive or intensive systems (Borja *et al,* 2006). Tilapia is a group of several species of the Cichlidae Family introduced in developing countries of tropical and subtropical regions with the purpose of obtaining a source of protein of low cost of production (Ibáñez *et al,* 2017). This is considered one of the fish with the greatest commercial future. But also the cultivation of this species is an activity that demands a large amount of natural resources, such as water, and represents one of the chains of which a great commercial future is projected.

Nowadays, renewable energy sources have become the main pillars of an energy policy, due to its sustainability (Lema *et al,* 2017). Given that there are technological advances that favor the use of these resources, it is necessary to implement this technology in the production processes that are carried out in fish farming. This would guarantee optimizing these processes, while saving natural water resources important for the environment.

For the adequate culture of tilapia a process of oxygenation of the water is required that does not occur naturally in lakes constructed by man. Therefore, it is necessary to increase the amount of oxygen in the liquid artificially, to achieve more efficient productions. Therefore, this process requires that the implementation be carried out in an appropriate manner. In order to guarantee this, it is necessary that there is a system that monitors, registers and controls in real time the level of oxygen in the lakes using the internet. This is what is intended to be done in this project through the design of a prototype.

The methodology implemented in the project is the SCRUM. It seeks the agile development of software, under a framework designed to achieve the effective collaboration of teams in projects (Navarro and Fernández, 2013). This methodology is composed of four phases: planning, staging, development and delivery. In planning, the vision is established, expectations are set and financing is secured. The staging identifies more requirements and is prioritized for the first iteration, in the implementation the system is developed and in the delivery the operation deployment is made.

In this way, the structuring of the project is done as follows:

Initially, the current situation of fish farming is contextualized, as well as the characteristics of the different parameters necessary to maintain an adequate aquatic habitat. Then the design and implementation of the control elements of the system is described, composed of the different physical structures and circuitry for the conditioning of the sensors and the acquisition of data. Then the programming of the software that allows the control and automation of aquatic habitat conditioning is developed, in addition to exposing the main application that allows visualizing and monitoring the parameters in real time of each of the physicochemical variables. Subsequently, the tests and results obtained corresponding to the operation of the prototype are summarized, and finally the conclusions and recommendations of the work carried out are presented.

2. MATERIALS AND METHODS

The department of Huila is one of the main producers of tilapia in the country. Many fish farms are being affected by the high mortality rate due to the lack of monitoring of the physicochemical parameters of water

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such as temperature (optimum range between 25 ° C and 28 ° C) and dissolved oxygen (optimum range between 5 and 8 ppm) (Goyenola, 2007).Therefore, it was decided to implement an innovative system with which it seeks to provide a technological tool to the fish farmer that will help him to reduce the mortality rate and improve his production. This system works through renewable energies by means of an autonomous photovoltaic system that are of great importance to counteract global warming, avoiding the use of conventional energies that depend on fossil fuels (Messenger and Ventre, 2010). This brings ecological nuances to the prototype. It also has the stage of adaptation of the sensors, the stage of data acquisition and information processing, and the stage of communication and visualization of data.

2.1 Electric power stage

The system in this stage works as shown in Figure-1. It is powered through a 20 W solar panel, with a 12 V voltage controller, connected to two batteries in series (6V and 4.2 A-h), bringing this voltage from the batteries to the circuit that is responsible for regulating and distributing the different voltage levels according to the system requirements.

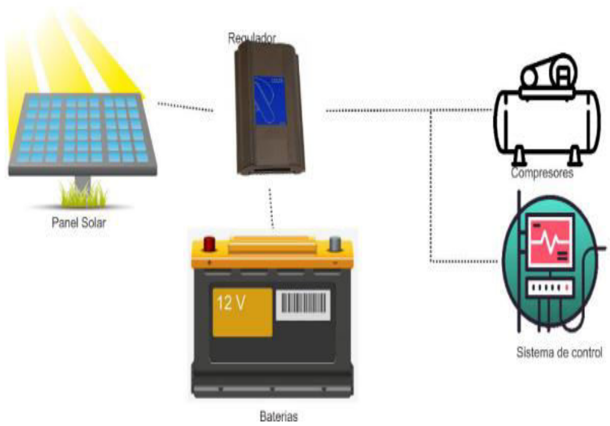

Figure-1. Electric power stage.

2.2 Adaptation of sensors stage and materials

The adaptation of the sensors by means of electronic components is not necessary, this is because the Raspberry Pi works at 5 volts DC, and the sensors used work at the same voltage, which facilitated the process.

In order to monitor the physicochemical variables that may cause negative effects in fish, sensor networks are being used. The sensors can be placed in the tanks. When some water parameter is not adequate, corrective actions are taken (Rocher *et al*, 2017).

To monitor the system temperature, the DS18B20 sensor was used. This is a high accuracy digital thermometer (±0.5°C) that has three terminals, two for power (red and black), and a DATA terminal (yellow) that transmits and receives the information bits.

In order to monitor the dissolved oxygen in the ponds, the Atlas Scientific sensor was used, which can send the information through USB communication, I2CM UARD. It consists of a polarographic electrode that measures the concentration of dissolved oxygen in water and aqueous solutions. A platinum cathode and an anode of reference silver/silver chloride in a KCI electrolyte. They are separated from the sample by a gas-permeable plastic membrane.

A fixed voltage is applied to the platinum electrode. As oxygen diffuses through the membrane to the cathode, it is reduced:

$$\frac{1}{2}O_2 + HO_2 + 2e- \rightarrow 2OH \qquad [1]$$

Oxidation occurs at the reference electrode (anode):

$$Ag + Cl- \quad \rightarrow \quad AgCl + e- \qquad [2]$$

The current is converted into a proportional voltage that is amplified and read by any Vernier interface.

2.3 Calibration of the dissolved oxygen sensor

After calibrating the module with the parameters established in the manual using oxygen from the atmosphere to perform this process, it is necessary to calibrate the oxygen sensor with a defined parameter or another sensor that its calibration has been carried out shortly after the calibration of the sensor or with a solution with 0% dissolved oxygen that comes with the purchased probe. The steps to perform this calibration are:

a) Connect the O.D module and the probe with the microcontroller or I2C connection to visualize it.
b) Synchronize the I2C or the microcontroller to the computer to visualize and be able to send commands to the communication module. The configuration should be 38400 bits per second, 8 bits of data, parity none, stop bits 1, flow control none.
c) Immerse the probe in the 0% oxygen solution.
d) Leave the probe submerged until the oxygen reaches 0.
e) After 5 minutes, with the code provided by the manufacturer for the Python software, the calibration is carried out. Enter the command: "cal, 0" to calibrate, the LED will light Cyan during the calibration, after 1.3 seconds the O.D will transmit "1" indicating that the order has been processed correctly.

The conditioning test is carried out in the early hours of the morning taking measurements every minute with the dissolved oxygen sensor "Atlas Scientific". In this case measurements are taken during 4 hours, (48 measurements), also measuring the temperature to make a comparison with Table-1 that shows me the theoretical values of dissolved oxygen concentration.

Table-1. Dissolved oxygen concentration values.

Temp (°C)	**D.O** (mg/L)	**Temp** (°C)	**D.O** (mg/L)
0	14.6	16	9.9
1	14.2	17	9.7
2	13.8	18	9.6
3	13.5	19	9.3
4	13.1	20	9.1
5	12.8	21	8.9
6	12.5	22	8.7
7	12.1	23	8.6
8	11.8	24	8.4
9	11.6	25	8.3
10	11.3	26	8.1
11	11.0	27	8.0
12	10.8	28	7.8
13	10.5	29	7.7
14	10.3	30	7.6
15	10.1	31	7.5

2.4 Calibration of the pH sensor

The pH sensor SEN0161 is an analog pH meter, specially designed for Arduino controllers. To use it, connect the pH sensor to the BNC connector and connect the PH2.0 interface to the analog input port of any Arduino controller.

The pH of the water varies between 6.5 and 8.5 (dawn). Most of these fish die in waters with a pH lower than 4.5 or higher than 10.5, this allows the pH to be corrected outside these intervals, to guarantee the non-decrease in fish production (Diaz and Vargas, 2017).

This sensor is analog and to be able to connect it to the microcontroller it is necessary that the signal goes from LOW to HIGH (off to on or 0 to 1). For this, it is necessary to convert the analog signal to digital. The output of the pH electrode in millivolts, and the pH value of the ratio is shown as follows (25°C):

Table-2. pH measurement values.

Voltage (mV)	**pH Value**	**Voltage (mV)**	**pH Value**
414.12	0.00	-414.12	14.00
354.96	1.00	-354.96	13.00
295.80	2.00	-295.80	12.00
236.64	3.00	-236.64	11.00
177.48	4.00	-177.48	10.00
118.32	5.00	-118.32	9.00
59.16	6.00	-59.16	8.00
0.00	7.00	0.00	7.00

2.5 Raspberry Pi

The Raspberry Pi, in addition to being versatile and of very low cost, is attributed functions as those of any desktop computer, integrating the necessary components of a common computer. It has several ports and USB, Ethernet and HDMI output ports allowing connecting the board with other devices such as screens and keyboards.

The Raspberry Pi offers a comprehensive experience for the user to decide what he wants to do with his computer, embarking on projects of the most diverse nature, such as home media centers, home automation, secondary computer, surveillance cameras, or any other application that requires more or less elevated processing.

2.6 Oxygen plant

It is a system of production and concentration of oxygen integrated in a light and compact unit that can be installed with spaces, adjustments and minimal logistics for applications in aquaculture industries. For its operation the water is taken to inject oxygen and leave it completely dissolved in the liquid. This equipment has a flow and pressure control system, alarm system for pressure, temperature and purity irregularities. All this for a reliable control of the operation.

The equipment requires a constant flow of water taken from a pond or lagoon where the aquaculture culture is, the water must be driven by an electric pump that guarantees the required flow in the process of oxygen saturation.

The integrated generator does not require civil works, it must be installed on a firm surface and preferably with a cover that protects it from climatic conditions. Fish projects with state-of-the-art technology are sustainable, profitable and allow a considerable socio-economic impact in the medium and long term.

Table-3. Specifications of the oxygen plant SP10INT.

Specifications	**Model SP10INT**
Flow L/m	5 lpm
Flow m^3/d	7.2
Length	39 cm
Width	42 cm
High	73 cm
Oxygen purity	90%+/- 3
Pressure	7 – 8 psi
Power	120V, 60Hz, 220-240V, 50Hz
Energy consumption	0.5 Kw
Sound	45 dB
Weight	28 Kg

2.7 IOT system hardware

The circuit is powered by 110V AC from the inverter in tank 1 and the conventional electrical network that also provides 110V AC in tank 2. This will be responsible for regulating and distributing the different voltage levels required by the system.

The hardware of the circuit consists of a level in which the circuit is in charge to adapt the signal coming from the sensors and the processing which is carried out in the Raspberry Pi. KORÉ is the chosen name for the device.

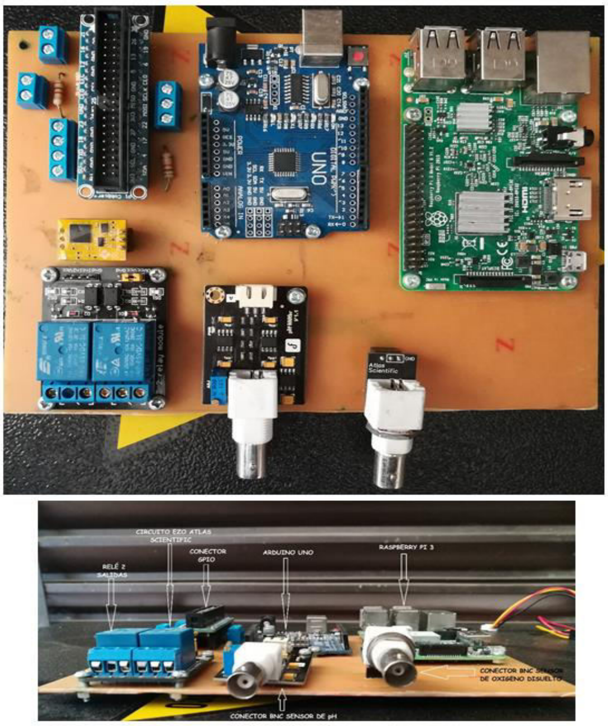

Figure-2. IOT system hardware.

2.8 Implementation of the floating system

Once the hardware implementation of the circuit is finished, it was proceeded to design and implement a floating system capable of supporting the weight of the sensors that the system has. The final product is the one shown below:

Figure-3. Floating test.

3. DEVELOPMENT OF SYSTEM SOFTWARE

3.1 Methodology used

For the development of the project the SCRUM methodology has been chosen, which allows to develop projects in a fast and organized way. This methodology requires a well-defined planning, a work team must be established, some objectives and these objectives will be divided into cycles (iterations) of maximum 20 days, holding short meetings of 10 minutes each day, to verify the progress, analyze the problems and quickly determine an action plan to solve them.
The SCRUM team is made up of:

- Product Owner: Is the owner of the product, determines the objectives of the product, this role will be played by Cándido Herrera, deputy director of SENA Angostura Node
- SCRUM Master: He is in charge of verifying that the SCRUM stages are carried out, engineer Gustavo Adolfo Perdomo was in charge of playing this role.
- Development Team: The development team was responsible for carrying out the entire process of creating the product, this role was played by Tania Katherine Mazabel and Yefferson Leonardo Torres, students of the Surcolombiana University.

For the correct development of this work methodology it was necessary the advice of Engineer Gustavo Adolfo Perdomo, consultant of the engineering and design line, who was the counselor in the process of execution of the project in the Piscicultural Unit of the SENA. It began with a meeting that allowed to talk about what was wanted to achieve with this project, to establish the objectives and establish the estimated time for the realization of this. With this it was possible to organize the amount of SPRINTS that were necessary to fully comply with the project's guidelines.

In the first sprint, the activity that was carried out was that of programming the Raspberry board through Python software. Although this work methodology was new, it was possible to work on the required objectives of this first sprint. Although it took a little longer than the estimated time, since the development of this part corresponded to one of the most important of the project, it was possible to reach important advances and adapt to this new methodology.

The Product BackLog that was established was:

- Reading of the variables (dissolved oxygen, temperature)
- Control of dissolved oxygen
- Programming the board
- Open source
- Time of development

Following this, a sprint backlog was established where the elements required to carry out the project in this first sprint were specified. These were:

- Reading of variables (oxygen, temperature)
- Oxygen control
- Use of Raspberry
- Use of Arduino
- Serial communication Arduino-Raspberry
- Development in Python

3.2 Graphical interface using qt designer

It was decided to carry out the development of the interface with the Qt Designer tool of PyQt, which is very similar to Java because of its design. This tool is very useful because it allows transforming it and using it as an engine of the Python interface through the Pyqt5 library. The reason why Python was chosen to develop the interface was the easy implementation with communication protocols, compatibility with all operating systems, especially the one used in this project, Rasbian and its GNU licensing that allows very low cost developments and ease.

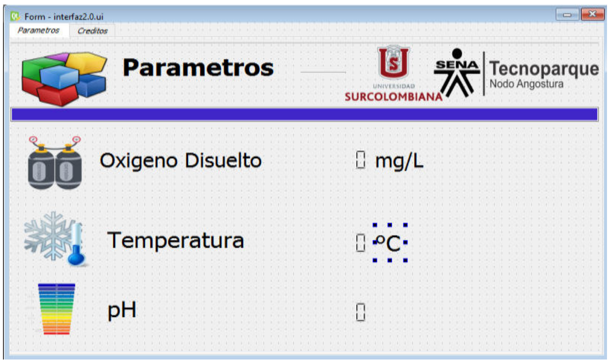

Figure-4. Measurement parameter interface.

3.3 Web application

The web application for the visualization of the physicochemical parameters of tanks 1 and 2 included the query module that is where the application is nested. There the registration of the variables through a graph can be observed.

This application is developed in PHP, integrated with a database of MySQL, using the design pattern MVC (Model View Controller), for the generation of graphics the JChar library is used.

The Raspberry Pi 3, or any device with an internet connection, sends or makes a request to the server, with the address www.cicefa.com. In the aforementioned request are the data, which are recorded in the database. There is the requirement of the physicochemical parameters recorded in the last request, to have more control it was decided to store the data of the parameters every minute, but in the application we can observe them every minute, every ten, every hour, or every 24 hours, according to the user's comfort.

In the graphs the variation of the parameters in a range of date established by the user you be checked. This to do the different comparatives for days, months or years.

The development of the web application did not represent more work, because the CICEFA platform is made framework type. The only thing that is done is to create the views, methods and SQL statements, and then arrange them according to the system requirements. The access for the reports was left of public character, which is to say that any person from any part of the world can consult the parameters that are being measured. It is restricted in terms of the registration of data, to avoid risking any type of hacking, or that any person can distort the stored data.

Figure-5. Web application interface.

3.4 Mobile application

A mobile application is a computer software designed to be executed on mobile devices such as tablets, smartphones, smart Tvs, Smartwatch, among others, in order to give versatility and easy handling by users.

To develop the mobile application Android Studio software was used, which is an integrated development environment that is used to create applications on the Android platform (Cruz, 2013). It is free software, which in addition to allowing development through Java code, can also be done through templates. As the mobile applications developed today, mostly have a base platform, it was guided by one that allowed Bluetooth communication with any device linked by serial communication (Bluetooth Terminal). This allowed to start with the connection with the device, sending and receiving data, and then make improvements using Java code so that the application will send by default the char "#" and the microcontroller will detect that this was the end of the string to do your data sending operation. The application is designed so that the input data is stored in the RAM of the mobile device and thus be able to graph them, in addition it will generate an alert if the last line sent is not within the optimal ranges of the monitored parameters.

Figure-6. Graphical mobile application interface.

3.5 Mail alarm

Because it was necessary to have more control of the system, it was decided to implement an alarm through Gmail. When the oxygen, temperature and pH are at critical levels, the system has the ability to notify the operator that it is happening and that it takes measures if the prototype fails to reach the desired parameters.

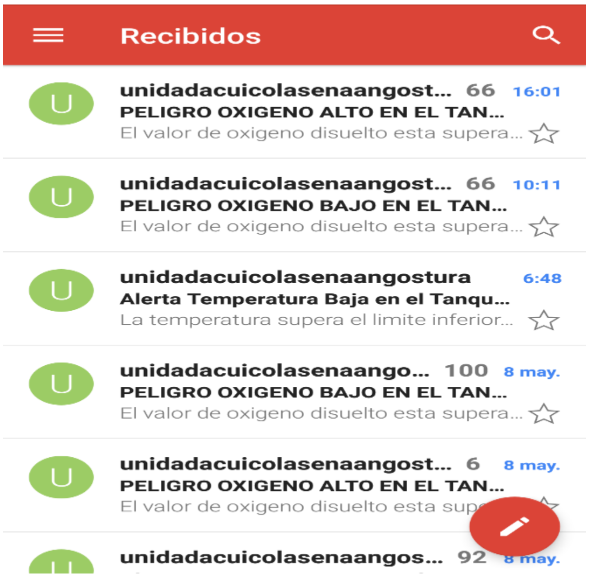

Figure-7. Alarm of undesired levels of parameters.

3.6 Quality of measurements

In order to corroborate the quality of the measurements obtained, the Portable Dissolved Oxygen Meter HI 98193 from HANNA INSTRMENTS was used as a standard.

Once the dissolved oxygen data is taken, 40 samples are used every 5 minutes, with the Atlas Instruments sensor, and the Hanna. In addition, this sensor takes samples of temperature, which corroborates the digital sensor Ds18b20 that is designed to accurately measure the temperatures in humid environments, in this way it was possible to validate the information by comparing data.

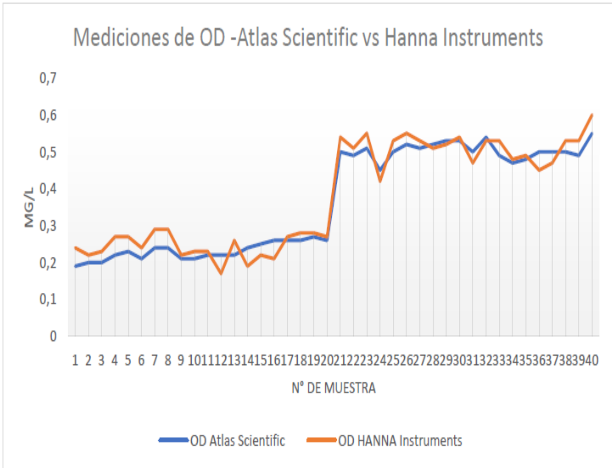

Figure-8. Correlation of dissolved oxygen measurements.

Table-4. Arithmetic mean of dissolved oxygen sensors.

Atlas scientific	0.367
Hanna Instruments	0.380

$$Relative\ Error = \frac{0.367 - 0.380}{0.380} * 100\% = 3.42\%$$

The HI 98193 Dissolved Oxygen Dissolved Oxygen Meter from the company HANNA INSTRUMENTS is taken as a standard, the data of the temperature sensor Ds18b20 and at the same time those of the HANNA are taken, these measurements are expressed in the following figure.

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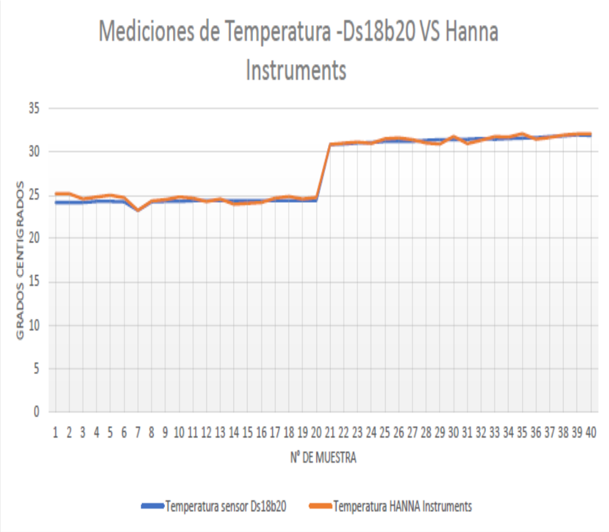

Figure-9. Correlation of temperature measurements.

Table-5. Arithmetic mean of temperature sensors.

Ds18b20	**27.859**
Hanna Instuments	27.985

$$Relative\ Error = \frac{27.859 - 27.985}{27.985} * 100\% = 0.45\%$$

To corroborate the quality of the measurements obtained in the pH measurements, a Digital measure was taken, which is calibrated in the SENA ANGOSTURA WATER QUALITY LABORATORY. Corroborating data, the following figure was obtained.

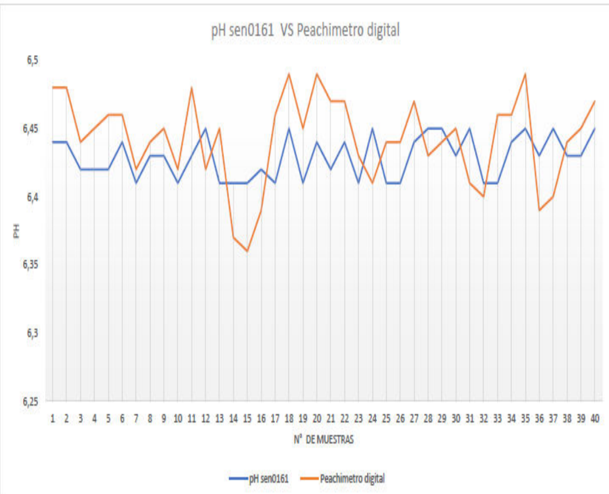

Figure-10. Correlation of pH measurements.

Table-6. Arithmetic mean of pH sensors.

pH sen0161	**6.429**
pH meter digital	6.594

$$Relative\ Error = \frac{6.429 - 6.594}{6.594} * 100\% = 2.5\%$$

4. RESULTS AND DISCUSSIONS

Taking into account the averages of the days chosen for the samples, it can be observed that during all the days extremely low values of dissolved oxygen were present in both tanks, while the temperature had an acceptable range.

Analyzing system data, it can be determined that oxygen levels in this crop decrease alarmingly at dawn from 00:00 hours until 8:00. This is because the fish and other microorganisms present in the lake increase oxygen consumption, however, it can be seen that in the evening, from 5:00 pm to midnight, the oxygen levels increase slightly.

Oxygen levels during the day remain stable, but critically low, which is because the tank does not have adequate recirculation. Since these ponds are artificial, they do not allow the growth of algae and aquatic plants that would help the production of oxygen through the process of photosynthesis.

Analyzing system data it is observed that temperatures between 00:00 and 04:00 most days have a tendency to be the highest of the day. However, it remains within optimal levels for cultivation.

The lowest temperature occurs mostly from 4:30 p.m. to 7:30 p.m. However, it is within the optimum range, this is because at this time the night begins to fall and the sun begins to dim.

Taking into account the statistical analysis and especially the coefficient of variation of the sample, it can be seen that the temperature has a fairly low percentage variation and that the tanks have no problem for the culture of tilapia by this parameter. This is because the Huila is located in a privileged geographical area and prone to the breeding of this species. On the contrary, dissolved oxygen does have a high percentage of variation, in addition to not meeting even the minimum optimum level for tilapia culture, due to the lack of recirculation, microorganisms and oxygen-producing algae.

The pH levels remain constant; this is because, in a pond of this type, the pH can take from one to three months to change only one unit.

5. CONCLUSIONS

A prototype of temperature, dissolved oxygen and pH monitoring was designed and implemented, and the amount of dissolved oxygen present in the pond was controlled, obtaining a record with a low error rate.

A mobile application was created through free software (Android Studio), where the farmer can wirelessly view the temperature, oxygen concentration and pond pH levels.

A Web application was created through the PHP programming language, where the fish farmer can visualize through the internet, the temperature, oxygen concentration and pH levels of the pond, as well as a history of the behavior of his crop.

The use of the SP10INT oxygenation plant is recommended, due to its correct functioning and excellent efficiency for small ponds like the one developed in this project.

This is a modern system, since it is powered through a photovoltaic system that takes advantage of the use of renewable energies, contributing to the solution of the climate problem, but also uses conventional energy; with this we ensure the correct use of the prototype.

Through the data obtained by the prototype and the validation of the same, it is concluded that the oxygen level is the parameter to which we must pay more attention. But with the inclusion of the control system it was helped to maintain an optimum range for the correct development of the crop.

All the stages of the implementation of the system worked properly, obtaining a functional and novel prototype for the fish sector that demonstrates the reduction of mortality levels which is harmful for the crop, and with this a higher productivity is ensured.

Due to the fact that the Surcolombiana region is the power in tilapia production, it is a good option to offer this prototype to small fish farmers, because it is low cost, efficient and easy to implement. In this way, fish production in our department will be translated into greater profitability.

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