



# Implementation of a IoT monitoring system applied to trout fish farming

## Implementación de un sistema de monitoreo IoT aplicado a una piscicultura de trucha

Tito Manuel Piamba-Mamian<sup>1</sup>  
Leidy Estefanía Zambrano<sup>2</sup>  
Luis Alexander Montaña-Ruales<sup>3</sup>  
Francisco Arturo Rojas-González<sup>4</sup>

<sup>1</sup>Corporación Universitaria Autónoma de Nariño (Colombia).  
Email: [tito.piamba@aunar.edu.co](mailto:tito.piamba@aunar.edu.co)  
ORCID: <https://orcid.org/0000-0003-2396-2088>

<sup>2</sup>Corporación Universitaria Autónoma de Nariño (Colombia).  
Email: [leidy.zambrano@aunar.edu.co](mailto:leidy.zambrano@aunar.edu.co)  
ORCID: <https://orcid.org/0000-0003-1971-8146>

<sup>3</sup>Member of the INMECNAR Research Group (Colombia).  
Email: [lucho961007@hotmail.com](mailto:lucho961007@hotmail.com)  
ORCID: <https://orcid.org/0000-0002-4431-3215>

<sup>4</sup>Mechanical Engineering student. Corporación Universitaria Autónoma de Nariño (Colombia).  
Email: [roiasgonzalezfranciscoarturo@gmail.com](mailto:roiasgonzalezfranciscoarturo@gmail.com)  
ORCID: <https://orcid.org/0000-0001-6452-4418>

Received: 08-07-2020 Accepted: 06-10-2020

**How to quote:** Piamba-Mamian, Tito Manuel; Zambrano, Leidy Estefanía; Montaña-Ruales, Luis Alexander; Rojas-Gonzales, Francisco Arturo (2020). Implementation of an IoT monitoring system applied to trout fish farming. *Informador Técnico*, 85(1), 3-19. <https://doi.org/10.23850/22565035.2937>

## Abstract

Colombia, due to the increasing production of rainbow trout, sees the need to augment its production processes, therefore, it must improve the production of eggs and fingerlings in fish farms to meet the demand for the final product. The current market is divided into meat production and the sale of fingerlings; therefore, it is necessary to implement a monitoring system in the initial stage of production (fingerlings) since this involves a high degree of mortality caused by its delicacy and factors unknown to the fish farmer, causing economic losses and even the closure of their businesses. When processes related to technologies and Industry 4.0 are identified, the "fourth industrial revolution", hardware and software components are put in place to strengthen production processes focused on improving user needs, and when talking about technologies, innovative ideas are developed concerning large factories, and therefore, costly economic projects. However, the digital transformation has been reflected in scenarios where specific modes are given, which provide a high return on investment by optimizing production. Because of that, the main objective of this research is to establish a construction system model oriented to the use of *Internet of Things* (IoT) techniques, identifying variables such as temperature, dissolved oxygen, pH, and real-time systems that allow rainbow trout mortality to be reduced in early stages (ova, larvae, and fingerlings), thus benefiting small producers, and satisfying the national and international demand.

**Keywords:** trout eggs; trout fry; mortality; rainbow trout; control; Industry 4.0; IoT Platform; rainbow trout.

## Resumen

La creciente producción de trucha arcoíris en Colombia requiere el aumento de sus procesos productivos. Por ello, se debe incrementar la obtención de ovas y alevinos en las pisciculturas para satisfacer así la demanda del producto final. El mercado actual se divide en la producción de carne y la venta de alevinos, de ahí, la necesidad de implementar un sistema de monitoreo en la etapa inicial de la producción (alevinos), debido a que esta involucra un alto grado de mortalidad ocasionada por su delicadeza y a factores que son desconocidos por el piscicultor, como el valor de pH, temperatura y oxígeno disuelto, entre otros, originando pérdidas económicas y hasta el cierre de sus negocios. Cuando se identifican procesos relacionados con tecnologías e Industria 4.0 “cuarta revolución industrial”, poniendo en marcha componentes de hardware y software, con el fin de fortalecer procesos productivos enfocados a mejorar las necesidades de usuarios, al hablar de tecnologías se generan ideas innovadoras concernientes a grandes fábricas y, por ende, elevados costos en proyectos. Sin embargo, a partir de la transformación digital se han plasmado escenarios en donde se da lugar a modestos propósitos, que aportan un alto retorno de la inversión en vía de optimización de la producción. Por lo anterior, la presente investigación tiene como objetivo principal establecer un modelo de sistema constructivo orientado en la utilización de técnicas *Internet of Things* (IoT), identificando variables en tiempo real como temperatura, oxígeno disuelto, pH que permitan disminuir la mortalidad de la trucha arcoíris en etapas tempranas (ovas, larvas y alevinos), beneficiando así a pequeños productores y satisfaciendo la demanda nacional e internacional.

**Palabras clave:** ovas; alevinos mortalidad; trucha arcoíris; control; Industria 4.0; plataforma IoT; trucha arcoíris.

## 1. Introduction

Pursuant to the Ministry of Agriculture, Colombia is considered the second largest exporter of fresh trout and tilapia to the United States (Ministry of Agriculture and Rural Development, 2016). Huila is the main department to generate more aquaculture production with 46 %, while Nariño and Putumayo contribute less with approximately 14 % (Computer Aided Engineering [IAC], 2018), however, their product stands out for its quality. This activity favors the generation of new jobs, entrepreneurship, and poverty reduction, due to worldwide trade (Food and Agriculture Organization of the United Nations [FAO], 2014). Besides identifying that natural fishery resources are limited and the demand in aquaculture will have to supply populations worldwide (Parra, 2019), aquaculture is represented by the production of tilapia, black pacu, trout, and shrimp, which has had a high development. In fish farming, Colombia has developed in recent years a production of circa 120,230 tons in 2017, with an annual growth of 9 % and employment generation of 6 % per year, with 36,069 direct jobs and 108,207 indirect jobs (IAC, 2018). However, it should be noted that economic losses have been frequent in the trout production process, particularly in the Aquaculture Company Acuimayo, which ranges from 80,000 to 100,000 eggs and the normal average of losses through the stages corresponds to 30 %, which is a considerable economic loss. Therefore, it is considered important to decrease the factor of uncertainty losses, and thus increase the producer profits.

Due to the expansion of trout cultivation in areas of the department of Nariño and Putumayo, it is necessary to strengthen practices through technical resources, that allow improving productive activities and even being able to use new technologies, such as the IoT, which is defined as the Internet of Things (*Internet of Things*), which refers to the interconnection of everyday objects with the internet, it is comprised by technologies such as sensors that enable the connection of the physical world with the digital one, and where the data obtained are processed and converted into information (IAC, 2018). This kind of technology may be implemented in artificial environments, such as ponds, which are suitable cultivation environments.

The Acuimayo Internacional fish farm is a microenterprise located in the town of Sibundoy, in the department of Putumayo, Colombia, which is dedicated to the trade of trout meat from the acquisition of eggs to obtain the rainbow or salmon-type trout. In this location, the work is carried out manually, which generates

an inefficient control in the handling and loss in the breeding stages. The trout breeding process begins from the stage of eggs, followed by larvae, fingerlings, and their development in young and adult trout, and ends in the harvest and trading, whereas the ova, the larvae and the fingerlings are deemed as the stages with the greatest risk and uncertainty due to the high mortality rate (FAO, 2014). This is due to the sensibility to changes of some critical variables present in the water, such as dissolved oxygen, temperature, turbidity, and pH that cause a mortality rate above 70 %. Therefore, this research has the purpose of proposing the implementation of an IoT and data collection system for the monitoring of the critical variables, thus fulfilling the objective of carrying out a study and the implementation of IoT technologies, in order to track variables that influence mortality in the early stages of growth of this species. Moreover, a practical goal is to obtain an analysis from the data obtained, to create a visualization tool (IoT platform) and an alarm system that warns about events in real-time. Finally, an analysis is established that highlights the advantages and disadvantages in the implementation of the proposed solution and, therefore, provides optimal results that benefit the company's production.

## 2. State of the art

The term Industry 4.0 emerged in 2011 in Germany. The purpose of this term is related to the discovery of the smart factory, the idea of achieving digitized manufacturing by obtaining interconnected processes through the *Internet of Things* (IoT). It is therefore known as the next level of the industrial revolution, which focuses on the *Industrial Internet of Things*. Industry 4.0 is the evolution of the industry, it is the union or merger of the industrial process with the internet through the implementation of intelligent components with their own features or digital identities to facilitate their remote monitoring, control, and maintenance (Basco; Beliz; Coate; Garnero, 2018). The technologies that are currently driving this industry are based on embedded systems with open source characteristics and System On Chip (SoC) devices, i.e., a component that integrates the necessary elements for a system to work. It is comprised of a processor, RAM, storage, and input and output controllers. Some examples are based on the integration of microcontrollers with SoCs, such as Arduino and Atheros interfaces (Arduino Yún), or peripherals, such as esp8266 and esp32. Other devices used include digital signal processing and instruction reduction graphics (RISC) modules that include an operating system, such as Raspberry. The use of IoT platforms is known for the fact that the devices are interconnected, generating their own ecosystem. In other words, the software connects the hardware, access system, and data networks that, overall, becomes the user interface (Cárdenas, 2016). The application of IoT technologies in fish farming processes is described below.




The world community faces the need of creating food and nutrition alternatives for a growing population with finite resources (Dussan; Vanegas; Chavarro; Molina, 2016). Given this situation, the World Health Organization (WHO), in the creation of strategies aimed at these needs, chooses to recommend the consumption of fish as a food supplement to the family basket. Dussan; Vanegas; Chavarro; Molina (2016) in their project of monitoring the physicochemical parameters applied to tilapia crops in their fattening stage, defined a system to determine the current mortality. Through their mobile application, they concluded that the variable that most influenced mortality was oxygen variation. On the other hand, Basto; Pinzón (2016) developed a monitoring system for rainbow trout crops, which monitors and corrects the condition in the habitat of the species. The measurement variables are dissolved oxygen, flow rate, and water temperature. Moreover, as a correction method, they propose a method of water recirculation. Data transfer is carried out through a Global System for Mobile Telecommunications (GSM) to a web platform. And Navarro; Padilla; Prías (2013) with its instrumentation system for measuring temperature, pH, and oxygen applied to an artificial tank, collected data in a text file (txt) for further analysis. In the case of Polania (2017), he proposes an automation system in medium and small fish farmers, whose purpose is to analyze the behavior of oxygen, pH and temperature variables to determine mortality rates in fingerlings. With the data obtained and through a fuzzy control, it is possible to determine the pulse width modulation (PWM) that triggers the oxygen pump. Rocher; Parra, Taha; Lloret (2017) propose a network of sensors for the recording of turbidity data and temperature in several tanks. They used the node called Flyport that sends the data to an HTTP server to visualize and create alerts as a security or control mechanism.



Fish meat production is obtained from two components: fisheries and aquaculture. The first one refers to the capture and the second one refers to the crop. Basically, aquaculture in Colombia is focused on four species. The main group is the tilapia or bream, as it is well known in Huila, which is the main national aquaculture producer. It is followed by trout and black pacu, which is the only native species out of the three (AGRIBUSINESS, 2015).

In Colombia, the main producing departments are Antioquia, Boyacá, and Cundinamarca, however, in recent years production has spread to Cauca, Huila, Nariño, and Santander, departments that provide lower production, but better quality. As per the Food and Agriculture Organization of the United Nations (FAO, 2020), at least 15.35 % of the country's fish production refers to trout, including red tilapia and black pacu. Regarding Acuimayo fish farming, we worked with specimens of French trout (a mixture of rainbow and salmon trout), from the initial cultivation process with approximately 500,000 eggs per month, through their breeding phases: larvae, fingerlings, juveniles, parr, and fattening. In this process, the estimated probability of mortality is presented from 10 % to 80 % reported by the company. The main problem identified in this context is the climate, insofar it is reflected in the level and turbidity of the channel derived from the San Jorge River, from where this fluid is provided in large volumes. Consequently, both in winter and summer, the flow of water is affected.

The production of rainbow trout or *Oncorhynchus mykiss* is divided into the following stages (Martinez, 2012):

**Table 1.**  
Trout stages

Stage	Description	Image (current research)
<b>Ova</b>	Considered the most critical stage. These eggs and their hatching under normal conditions can take between 10 to 15 days in incubation.	
<b>Larvae</b>	It is considered the stage where the larva leaves the yolk sac, from here, it begins its external breeding.	
<b>Fingerling</b>	Fish measure between 3 to 10 cm, at this stage they already have adult characteristics, they are more active and can catch their prey.	

Stage	Description	Image (current research)
<b>Juvenile</b>	The fingerlings weigh an average of 20 to 100 g and their size ranges from 10 to 15 cm.	
<b>Fattening</b>	After 15 cm it is considered suitable for harvesting.	

Source: Martinez (2012).

Within trout production, the following physical variables are identified (Table 2):

**Table 2.**  
*Physical variables*

Variable	Description
<b>Temperature</b>	The recommended optimal range for breeding should be between 10 to 17 °C. Lower values affect the development and higher values increase the spread of diseases.
<b>Dissolved oxygen</b>	The recommended oxygen concentration value should be above 5.5 mg/L. Lower values cause stress effects, affecting growth and causing the death of the fish.
<b>pH</b>	Aquatic environments with slightly alkaline pH are recommended. The optimal range should be between 7.0 and 8.0. Values above 9.0 and below 6.0 can cause diseases in the gills that cause the death of the fish.
<b>Turbidity</b>	Characteristic of the water when it loses its transparency, due to suspended particles, which obstruct the respiratory system of the fish causing diseases in the gills and the death of the fish.

Source: Perú Sea Institute [IMARPE] (2015).

### 3. Methodology

Like any research process, considering the need, the appropriate methodology must be selected to find possible solutions, therefore, this project is focused on descriptive and field research. During this research classified as descriptive, a case study is selected, which is the mortality in ova and fingerlings. Next, the company is specified, and that is the location where the context for the field research is identified. In this case, the Acuímayo fish farm provided its facilities. After defining the need, we proceeded to the collection of data based on the theoretical framework, such as books, websites, articles, and journals, inter alia, which enabled us to identify

which factors are associated with behavior and mortality. The information is then classified and the critical variables in trout breeding are defined.

Figure 1 presents a diagram for a possible solution. This diagram shows blocks of sensors that capture the changes in the foregoing variables. Sensor implementations are made in tanks 1 and 2. The data obtained goes to the processing module, in this case an Arduino mega, and is transformed into information and displayed in the field by means of a Liquid Crystal Display (LCD). In the case of IoT, the module is added with an 8266 SoC that uses WiFi protocol. It is linked to the Arduino and the data or information obtained is sent to an IoT platform to then be viewed by the operative through the Internet.

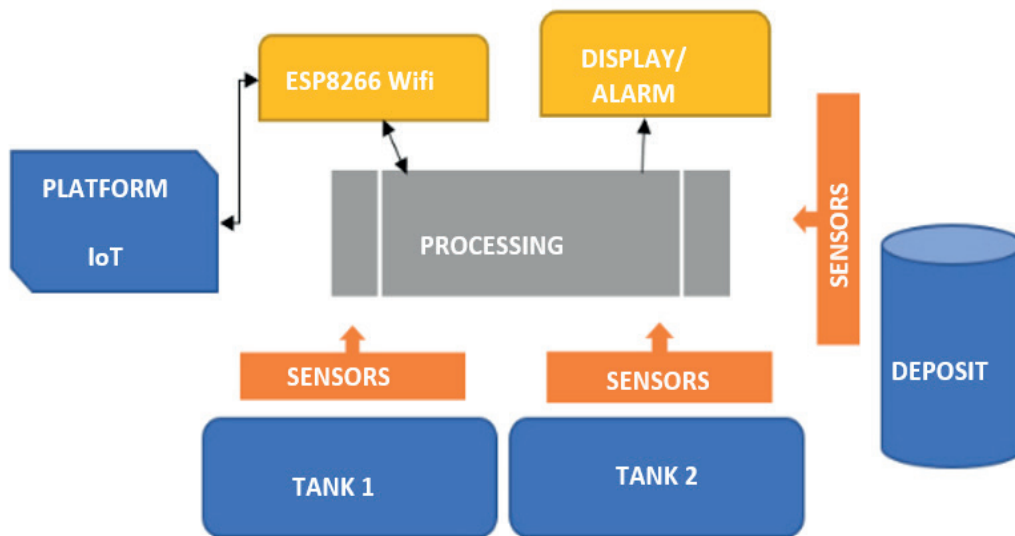


Figure 1. Proposed architecture for system implementation  
Source: own elaboration.

From this information, an IoT system was obtained to monitor variables such as temperature, oxygen, pH, and turbidity. In the selection of technologies for data capture, visualization, and processing, a comparison of characteristics, prices, user-friendliness, and robustness was made. Regarding the display, it is divided into field, through an LCD screen that shows the value measured by the sensors and the use of an IoT platform. For the development of the research, a test tank with fingerlings (Figure 2) was selected whose water came directly from the San Pedro River.



Figure 2. Breeding tanks, Acuímayo company  
Source: own elaboration.

After determining the work area and variables, we then proceed to select the sensors described below.

**Temperature:** for the selection of this sensor, the measurement range was defined, which is submersible in water and wherein it was easy to interpret the data obtained. Therefore, a digital probe type sensor with reference 18b20 was selected, which is characterized by using stainless steel. Its measuring range is -55 to 125 °C (Figure 3) (Maxim integrated, 2019).



*Figure 3. Temperature sensor 18b20*  
Source: own elaboration.

**pH:** a sensor with working characteristics in low temperatures and with applications in aquaculture and easy to acquire was required, therefore, an analog sensor was selected, with a calibration interface and with a medication range from 0 to 14 (Figure 4) (DFROBOT, 2019a).



*Figure 4. pH sensor*  
Source: own elaboration.

**Turbidity:** for the measurement of this variable, a sensor is required to work in rivers, wastewater, and aquaculture, with a measurement range between 0 to 3000 NTU, where the Nephelometric Turbidity Unit (NTU) is the unit that measures turbidity in a fluid, and which are quantified in mg/L or PPM (parts per million) (Engineering , 2019). Based on the above characteristics, the sensor from the manufacturer DFROBOT was selected (Figure 5) (DFROBOT, 2019b).

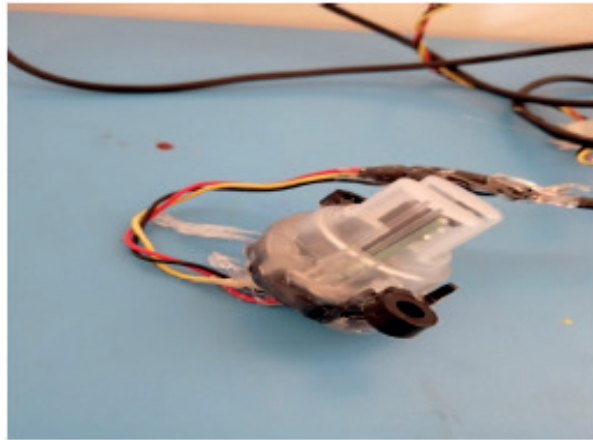


Figure 5. Analog turbidity sensor  
Source: own elaboration.

**Dissolved oxygen:** for the selection of the measuring device, a sensor is required that measures the dissolved amount of oxygen and the percentage of saturation in the water. It must have applications in hydroponics, aquaculture, and environmental monitoring. The sensor that meets the above characteristics, besides its easy acquisition, is from the company ATLASCIENTIFIC. Its communication is digital, and its measurement range is from 0 to 100mg/L and 0.1 to 400 % saturation (Figure 6) (ATLASCIENTIFIC, 2019).



Figure 6. Dissolved oxygen sensor  
Source: own elaboration.

### 3.1. Acquisition and adaptation of signals

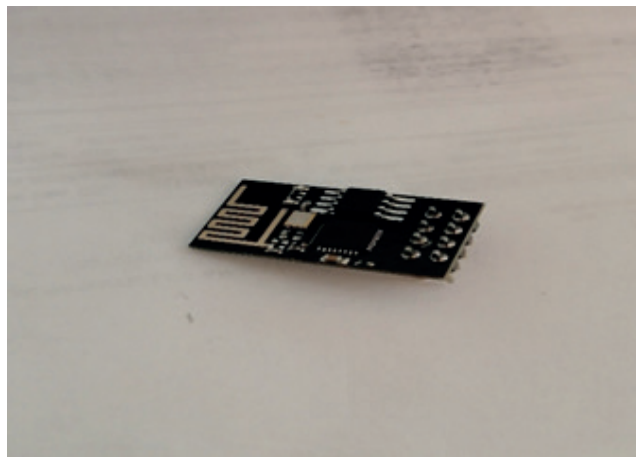
Arduino is an open-source electronic platform that is based on hardware and software devices. They are user-friendly tools, easy to use and are used in research projects due to their applicability. In their hardware devices, they differ in the amount of input and output pins, the kind of communication and processing speed, inter alia (Arduino, 2019). The selected processing module is the Mega 2560 board (Figure 7). The purpose of this selection is due to the processing speed (16Mhz), and its physical communication ports UARTs (serial communication RS-232) insofar, in the selection of components, its hardware connectivity requires this communication and 54 digital pins (input/output). Moreover, Arduino makes it easier to obtain sensor libraries and connect with hardware elements (Arduino, 2019).



*Figure 6. Arduino Mega 2560 in its mini version*  
Source: own elaboration.

## 4. Communications

For the use of IoT, Acuímayo has a satellite internet connection. And it also has a WiFi router, therefore, the WiFi communication protocol is selected and it must be linked to the Arduino board. For this purpose, the ESP8266 module (Figure 8) was used, which is a low-cost WiFi chip that works with the TCP/IP protocol (Arduino, 2019).



*Figure 8. WiFi communications module ESP8266*  
Source: own elaboration.

## 5. Display and IoT platform

The system used two methods as a means of communication. The first method used for field visualization is based on the use of a 3.5-inch LCD with UART communication as shown in Figure 9 below.

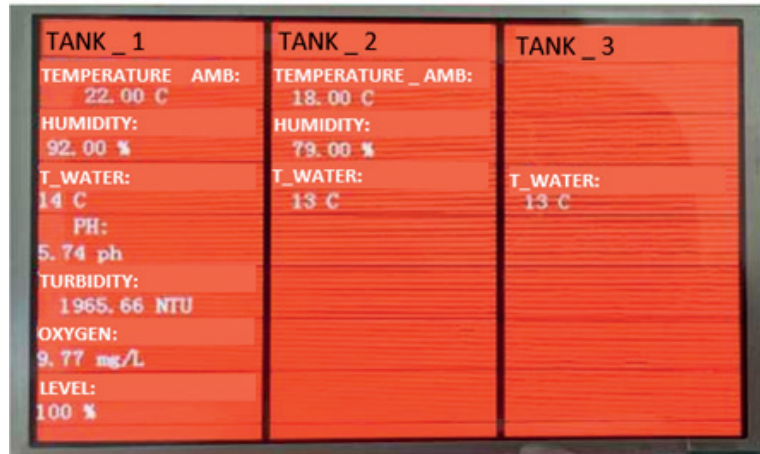


Figure 9. Field data visualization  
Source: own elaboration.

The second visualization method is based on the use of IoT platforms. With such purpose, the number of connection devices, data acquisition time, data storage, form of visualization, and ease of use in its demo version are considered. The IoT platform selected was ThingsBoard, which is an open-source, easy-to-use platform that enables swift development, IoT project management and scaling (ThingsBoard, 2019). This platform, in its demo form, enables the connection of six devices and the minimum range of data reception is one second. Moreover, its demo has no expiration compared to others. Figure 10 shows the design used for the variables monitoring in Acuimayo.



Figure 9. Dashboard or IoT platform applied to monitoring  
Source: own elaboration.

Besides, it has the feature of creating alarms and notifications using Telegram, which is an instant messaging system similar to WhatsApp. Telegram bots are software-operated Telegram accounts that are not operated by people, some of whom have artificial intelligence features. Its functions include teaching, playing, searching, and transmitting until integrating with IoT services or commands. Figure 11 shows the use of Telegram bot as a warning system for alarms generated by the platform.

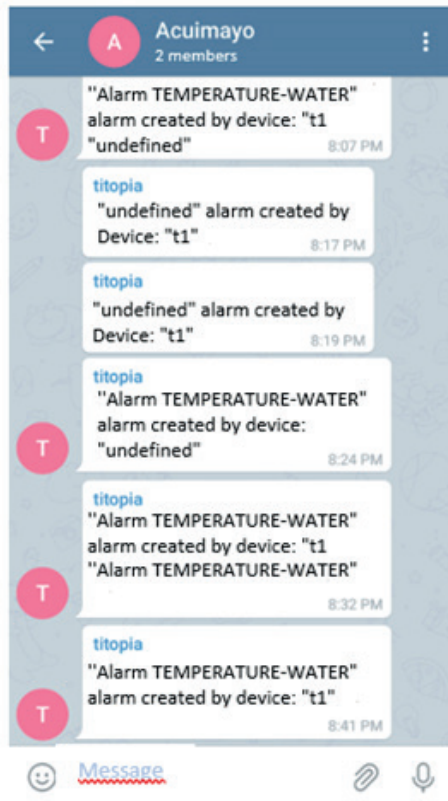


Figure 10. Alarms through the Telegram application  
Source: own elaboration.

## 6. Acquisition and calibration processing

After obtaining measurements or data from the use of temperature, pH, turbidity, humidity, and dissolved oxygen sensors, the next step is calibration which consists of eliminating erroneous data and obtaining valid data. For such purpose, the information provided by the manufacturers is used and data sampling is carried out to eliminate data (of higher and lower value) and reduce measurement error. An example thereof is the adequacy of the turbidity sensor whose interpretation is related to NTU units and is quantified in mg/L or PPM, where the range is between 0 and 3000 NTU (from lowest to highest turbidity) (Engineering, 2019). The second-order equation representing the ratio between turbidity and voltage (Equation 1 taken from Engineering, 2019) is as follows:

$$y = - 1120.4x^2 + 5742.3x - 4352.9$$

Where x corresponds to the voltage delivered by the sensor, and the variable y corresponds to NTU units (Figure 12).

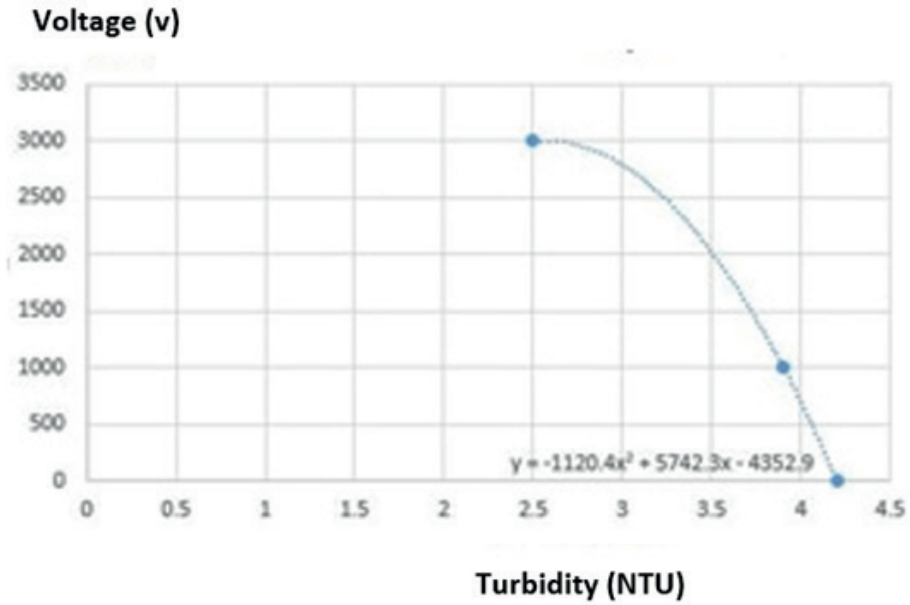


Figure 12. Ratio between turbidity and voltage  
Source: own elaboration.

## 7. Results

By venturing into the aquaculture sector, especially in the company Acuímayo, we managed to understand how the stakeholders traditionally or empirically try to improve their processes through the trial and error method, which can obtain long-term benefits and other partial or total losses of their trout crops. To solve this situation, an IoT system was installed to monitor the variables of water and environment temperature, humidity, dissolved oxygen, turbidity, and pH in the fingerling stage (Figure 13).



Figure 13. Monitoring system implemented in fingerling tank  
Source: own elaboration.



Figure 14. Fingerlings tank with increased turbidity in the water  
Source: own elaboration.

The installed system presented the following information: the water temperature does not vary and remains in the ideal range for fingerlings (11 to 13 °C). The turbidity of the water increases, due to natural factors caused by rains or landslides. This causes clogging of pipes with mud, therefore, it causes death to the fingerlings due to obstruction in their gills (dirt), due to the reduction of oxygen, or due to starvation, because they cannot see the food. With the turbidity sensor, early alarms are generated to reduce mortality through a recirculation system. Figure 14 shows the turbid water that reaches the breeding ponds.

Through the oxygen sensor, the conservation of ideal conditions is monitored. The measurement obtained ranged from 8.0-9.5 mg/L. The average population in each tank is 100,000 fingerlings, due to factors such as river overflows, and turbidity increases causing mortality rates that ranged between 20 % and 50 % (Figure 15).



Figure 15. Fingerling mortality due to the turbidity of the water  
Source: own elaboration.

The main water cut-off method in the case of increased turbidity (valve closure), also causes a mortality rate. This uncertainty has been present in the company because it was a possible solution to prevent mud from entering the ponds. To determine the possible cause, the following test was performed: at the beginning of the test, an initial value of 9.5mg/l of oxygen was recorded, then the main source of water in a pond was suspended. Subsequently, after 20 minutes the oxygen measurement was 7.22 mg/L (minimum recommended threshold). Therefore, we were able to conclude that the lack of oxygen causes mortality because Acuimayo usually cuts the water source for more than 60 minutes (turbidity duration). The immediate solution was the implementation of a blower system, which consists of an air blower that, using hoses and diffusers (Figure 16), is distributed

to each tank to create air bubbles and increase the oxygenation time in the tank. Upon the installation of this system, we managed to record that the oxygen was restored to levels between 6.9 mg/L and 7.2 mg/L, which decreased mortality, ensuring turbidity reduction in the system. Initially, the measurement was 1965 NTU, but with the blower system it was reduced by 973 NTU.



Figure 16. Implementation of blower and membrane for producing air bubbles  
Source: own elaboration.

The behavior of fingerlings in the initial conditions (9.5 mg/L), was distributed in the tank and was stationary (Figure 17). However, as oxygen was reduced, their behavior changed and they became more linear (Figure 18). Future work may include methods with machine vision or other procedures to detect the absence of oxygen.

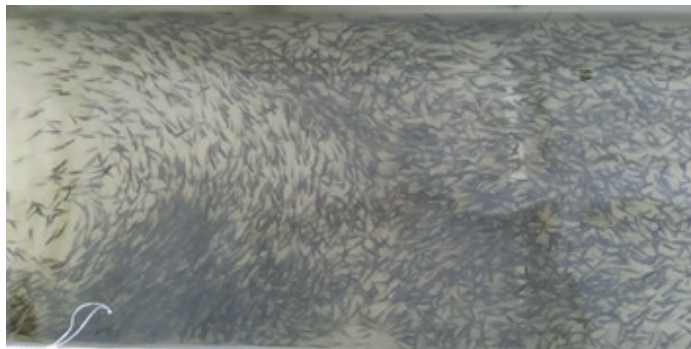


Figure 17. Behavior of fingerlings with 9.5 mg/L oxygen  
Source: own elaboration.

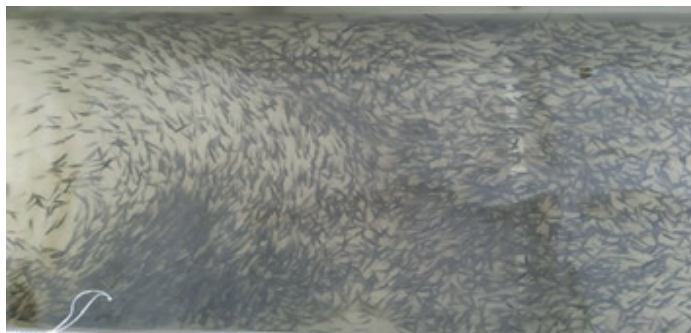


Figure 18. Behavior of fingerlings with 7.2 mg/L oxygen  
Source: own elaboration.

The data obtained by the sensors (Figure 19), were stored in a platform server, to create Bigdata. Afterwards, considering the resulting analysis, the purpose was to develop the control stage of the system.

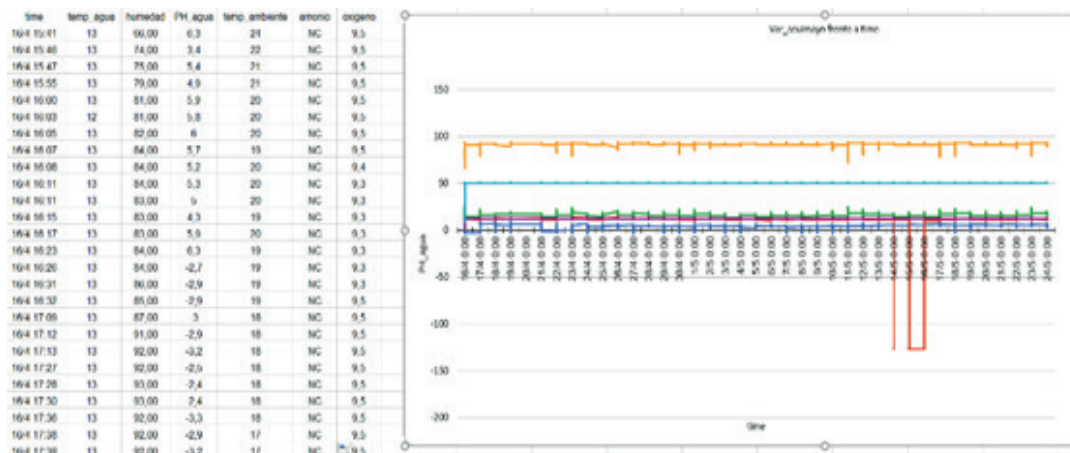


Figure 19. Sensor data stored in the cloud  
Source: own elaboration.

## 8. Conclusions

The implementation of different strategies for the taking and analysis of variables that affect the environment and aquaculture development provides the opportunity to generate stability within developing companies. Furthermore, it enables the use of state-of-the-art technology at a low cost, due to the fact that the components that comprise the system are easily available in the current market. The results obtained, despite an initial cost, and the introduction of new technologies to the aquaculture process, offset the initial investment compensated through the reduction in trout mortality, thus reducing production costs and economic losses. When implementing technological solutions from the fourth revolution, the factor of internet connectivity is a major drawback, and this is the case of Acuímayo which has a poor satellite connection.

According to the results shown, and with the purpose of reducing mortality and reducing economic losses in Acuímayo, solutions were implemented in order to know, monitor, and improve the development environments of the rainbow trout, in order to implement automation systems, such as water recirculation control by monitoring turbidity, or the air system by activating the blower. The introduction of technological progress, such as remote monitoring using IoT platforms, has facilitated surveillance for trout providers, even at night. Furthermore, our work showed that the behavior of the fingerlings in the tanks varies according to the amount of oxygen. When the amount of oxygen is greatest, they are distributed circularly in the pond, as the oxygen is reduced, their displacement becomes linear. The implementation of strategies to control the variables currently monitored in this fish farm is considered in the next stages of the study.

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