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VISIÓN ELECTRÓNICA

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VISIÓN ELECTRÓNICA

Design and construction of an automated system for NFT aquaponic culture of Red Carp and Crespa Lettuce

Diseño y construcción de un sistema acuapónico automatizado para cultivo acuaponico NFT de Carpa Roja y Lechuga Crespa

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Abstract: The use of technological tools to automate and monitor animal and vegetable crops has become a fundamental support for the quantitative and qualitative growth of sustainable food production. Therefore, the optimization of such processes developed in traditional facilities guarantees their efficiency, as well as that of inputs and products. In this sense, this alternative consists of the design and construction of an automated aquaponic system located at the SENA's Center for Agricultural Biotechnology (CBA), through the automation of the NFT aquaponic culture process to produce Red Carp (Cyprinus carpio) and Crespa Lettuce (Lactuca sativa), applying low and medium cost industrial technologies. As a result, reliable statistics are established in real time to evaluate the biomass growth of fish and plants in a given time, adding efficiency to the process compared to traditional soil seeding.

Keywords: aquaponics, automation, design, process, sustainable

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Resumen

La implementación de herramientas tecnológicas para automatizar y monitorear cultivos animales y vegetales, se ha convertido en un apoyo fundamental para el crecimiento cuantitativo y cualitativo de la producción sostenible de alimentos. Por ello, la optimización de dichos procesos desarrollados en instalaciones tradicionales garantiza su eficiencia, así como la de los insumos y productos. En este sentido, esta alternativa consiste en el diseño y construcción de un sistema acuapónico automatizado ubicado en el Centro de Biotecnología Agropecuaria (CBA) del SENA, mediante la automatización del proceso de cultivo acuapónico NFT para producir Carpa Roja (Cyprinus carpio) y Lechuga Crespa (Lactuca sativa), aplicando tecnologías industriales de bajo y mediano costo. Como resultado, se establecen estadísticas fiables en tiempo real para evaluar el crecimiento de la biomasa de los peces y las plantas en un tiempo determinado, añadiendo eficiencia al proceso en comparación con la siembra tradicional en suelo.

Palabras clave: acuaponía, automatización, diseño, proceso, sostenible

1. Introduction

Aquaponics can be understood as a multi-trophic process that involves an interaction between an aquaculture production system under a recirculation scheme (RAS) [1]; a hydroponic system for plant growing, in any of its different configurations (with or without substrates) [2]; and a nitrifying system composed of bacteria that help to decompose the nutrients found in the water [3]. To achieve its proper functioning, techniques have been developed to adapt sub-systems of filtration, oxygenation and sedimentation [4], allowing the evolution of this cultivation scheme and making it an innovative alternative for sustainable food production [5].

This farming technique is based on the use of waste and food that is not consumed by aquatic species, taking them through a decomposition process in which elements such as ammonium and nitrogen are transformed by nitrifying bacteria [3]. The effluent water resulting from this process is delivered to plants, absorbing and fixing organic compounds. At the end of the process, the water leaving the hydroponic system can be reused with a recirculation system that distributes it to the fish tank [6].

Currently, aquaponic systems have several significant challenges ahead in order to reach the profitability and safety of other cultivation methods [7]. According to [8], nutrient regulation, ammonium conversion, water exchanges and therefore the standardization of these processes are the main objectives to achieve this goal

Taking into account the above considerations, different works have been carried out to investigate the behavior of the system and understand it from different perspectives, from the study of water and waste management [6], the physical-chemical modeling of the interactions (fish, plant, bacteria) [9]-[12], the hydraulic flows given through the pipes [13], to the monitoring of bioclimate and climatology [14], [15]. Therefore, according to the review carried out by [16], it states that measuring instruments, actuators and programmable controllers are being deployed in order to monitor and control aquaponic systems in controlled trials for different aquatic and plant species.

Works such as [17], implement water level sensors in order to monitor the fish tank and issue alerts in case it is necessary to open or close valves to perform recirculation tasks; DS18B20 submersible temperature sensors with the capacity to measure up to 125°C, coated with stainless steel that through programming read and send data to controllers such as Arduino to compare with set points or references, sending signals to water heaters to increase or decrease the temperature; pH probes responsible for measuring hydrogen ions to determine the acidity or alkalinity of the water, alerting the user about the quality of the environment of fish and plants.

There is a strong relationship between temperature and dissolved oxygen, as the water warms up it tends to retain less oxygen, on the other hand, as the fish feed this can be reduced, arising the need to compensate by oxygenation methods such as water drops or aerators. Although dissolved oxygen DO is a very important variable is little reported in research due to the high cost of sensors, in the case of [18], the use of Atlas DO probes distributed in nodes (communicating different stations) with TCP/IP connection to a Raspberry Pi controller which reads and translates the signal to control aerators as required is presented.

Electroconductivity in aquaponics is related to the salinity of the water, and in the case of fish it represents an important element since, depending on its values, the water may be cleaner or polluted [5]. As reported by [19] in their measurements with EC/pH sensors of HANNA Instruments, high levels of electroconductivity in nutrient solutions for basil (Ocimum basilicum L.), cabbage (Brassica oleracea L.), chili (Capsicumannuum L.), and cherry tomato (Solanum lycopersicum L.) allow obtaining greener leaves and greater heights compared to fertilizers with low levels.

In industrial aquaponic systems, knowing the water flow allows estimating the capacity of mechanical filtration and biofiltration, as well as determining the availability of nutrients for the plants. To achieve the above, using computational mathematical models such as those described by [10], [20], an algorithm is generated in which the best culture environment for certain species of fish and plants is established, then sensors and actuators are adapted in conjunction with a controller that will be evaluating the model and making adjustments according to the levels measured by each sensor.

Although measurement and control are fundamental, access to information is a critical factor to understand what is happening in the system, that is why IoT technologies are taking strength in the field of aquaponics, [21], [22] have implemented a data acquisition and control system in conjunction with web and mobile applications through the integration of web servers, receiving information either by GSM, WiFi or wired networks and displaying it in applications that allow the user to know the status of the system at any time.

On the other hand, technological innovations not only depend on instrumentation, automation and control, the use of alternative energies in aquaponic systems that are commonly found in non-interconnected areas are equally important, studies such as [23] show the use of an automated aquaponic system powered by solar panels. Starting from a monitoring system of air and water temperature, relative humidity, light, pH, level sensors, dissolved oxygen, electro conductivity and turbidity, passing through conditioning circuits to enter a microcontroller that through programming in LabVIEW analyzes and controls actuators such as water pumps, aeration, heaters, dispensers and fans, ending with an integration through GSM that sends data to mobile platforms.

As has already been seen throughout the background, in addition to previous developments in aquaponic systems and the problems that have been identified to maintain an optimal balance in the exchange of nutrients between aquatic and plant species, the trend towards modeling, instrumentation and control to understand and take full advantage of the synergy produced by each of its elements is beginning to be identified.

Most of the aquaponic systems developed in Colombia are manufactured in a traditional way, therefore they are controlled in an empirical way, reducing the stability of the system and consequently making it inefficient [24], even increasing the mortality of fish and plants in cases where there is no knowledge about the current state of the aquaponic environment.

According to the above, the present project is proposed as an alternative to optimize the traditional processes, designing and building an automated system that introduces low and medium cost industrial technologies through a modular network composed of a central node and a peripheral one in order to monitor, visualize and control the status of the defined variables (pH, turbidity, dissolved oxygen, temperature and level) in addition to the frequency and duration of the water recirculation cycles. This in turn allows establishing reliable statistics in real time (and storable) for future evaluations of the biomass growth of aquatic and plant species in a given time when compared to traditional planting in soil.

2. Materials and Methods

2.1. Aquaponic System Sizing

The project starts with the identification of the aquaponic system prototype managed in the SENA CBA facilities. A data gathering on the physical dimensions of the aquaculture systems, including the equipment already installed such as tanks and pumps that compose it; and hydroponic NFT, considering the hole diameters for plants and their distance between centers, in addition to the layout of the pipes along the entire structure including the recirculation system. Taking into account the collected data and the crop management guidelines, the measured and controlled variables are established in order to select the instruments used for the automation, placing them in the critical points of the process, all this in conjunction with the design of the control system.

To carry out the 3D dimensioning, Solid Works software is used, adding each of the components of the system, including pipe connectors and support structures that hold in position the hydroponic piping network.3. Results

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

Additionally, a P&ID diagram is generated in the P&ID Designer software, being the basis for the selection of instrumentation and subsequent identification of the control loops that wilI be taken into account for the final solution design.

2.2. Characteristics of red carp (Cyprinus carpio) culture

Production

Due to its nature, this species has the capacity to adapt to a wide range of tropical zones, achieving optimal development in lentic environments such as the reservoirs used in aquaponics [25]. Due to its capabilities and requirements, this species can be adapted for cultivation in the SENA CBA system. Next, the critical physicochemical and environmental parameters, taken into account for the development of the automated prototype, are defined and identified.

Stocking density

The aquaponic system found at SENA CBA was designed for super-intensive culture, capable of hosting 30 to 150 fish/m^3 with continuous recirculation periods to ensure proper oxygenation and waste removal. According to previous analysis of the system [26], to achieve this, an aeration rate of 0.62 m^3 of air per ton of biomass and a recirculation flow of 0.002 m^3/min is established.

Dissolved oxygen

In the management of physicochemical parameters in fish, one of the most important is oxygen, the degree of saturation being directly proportional to temperature and pH [26]. Thus, based on several culture cycles, [27] reports that the optimal range for fish growth in the system should be greater than 4.5 ppm or 4.5 ppm.

Additionally, to avoid reductions in the oxygen concentration in the water (in conditions of super-intensive stocking densities), adequate management should be carried out for the removal of decomposing organic matter, uneaten food, waste and suspended solids in general. For which a daily maintenance is performed on the tank [28].

Temperature

Fish, being poikilothermic animals (their body temperature varies according to the temperature of the environment in which they are found), require adequate temperature management to maintain well-being, avoid stress behaviors, deficiencies in their feeding and consequently death in the population [29].

According to reports by [25], for carp farming the adequate range can vary between 28℃ and 32℃, supporting for short periods of time up to 5℃ below the recommended values. Depending on the temperature, effects directly related to fish metabolism can be seen, for example, at high temperatures the metabolic rate is higher, producing an increase in oxygen consumption; while at low temperatures a lower metabolic rate can represent a drop in feed consumption [26].

Potential of hydrogen (pH)

Being the concentration of hydrogen ions in the water, the potential of hydrogen in the water represents another critical factor to observe and maintain at adequate levels for the fish. According to [5], [30], the optimal range for fish growth and reproduction is 6.5 to 9.0, values above or below can produce behaviors such as lethargy which in turn causes lack of appetite and retardation in both growth and reproduction [26].

2.3. Characteristics of Crespa Lettuce (Lactuca sativa) culture

Normally, in NFT aquaponic systems it is convenient to use vegetables or herbs, emphasizing the product to be marketed (in this case its leaves) and its growing cycle (short cycle) [31]. According to the above, in the SENA CBA system, Crespa lettuce is used because of its wide documentation and use in experimental trials in aquaponics.

Its cultivation cycle is of short duration, from 25 to 45 days, and starts from certified seeds placed on seedbeds with peat as substrate. During this first growth period, they are supplied with as much light as possible, maintaining stable conditions of temperature, humidity and irrigation [2].

Once these seeds reach their germination stage and have additionally reached 10 cm in height, they are taken to the foams of the NFT aquaponic system. Taking into consideration the dimensions of the pipes, the seedlings are introduced in cubic sponges of 60mm x 60mm x 20mm (inside a longitudinal cut in the center).

Already in the pipes of the system, the Lettuce are adjusted to the production cycle of the Carps in conjunction with Biofloc, referring to the recirculation flow, their respective cycles, the water replacements, the alkalinity conditions and the concentrations of the elements derived from nitrogen.

2.5. Instrumentation, Sensors, Actuators and Controllers

Taking into account the sizing of the system and its management for the growth of fish and plants, the selection and structuring of the instrumentation for process automation is produced, choosing sensors in order to measure different values, actuators to regulate the recirculation cycle, oxygenation and temperatures and finally the required controllers to automate the process according to the desired parameters. All of the above was based on the systematic review carried out previously.

Sensors

Sensors were selected to measure the following variables: pH, dissolved oxygen, temperature, turbidity, flow and level, as shown below along with an illustrative image and their main characteristics (Table 1).

Table 1. Sensors selected for the automated aquaponic system

Sensor	Characteristic	Value
 **pH probe SZ1150**	Measuring range	0 – 14 pH
	Operating temperature	0 – 100 ℃
	Pressure	10 bar
	Connection type	4 Poles
	Connection to process	¾” NPT
	Power supply	9 – 36 VDC
 **pH transducer PH3630**	Operating temperature	-10 – 120 ℃
	Output	4 – 20 mA
	Connection to process	Rail DIN
	Power supply	10 – 30 VDC
 **Dissolved oxygen probe OD8525**	Measuring range	0 – 20 ppm
	Operating temperature	-5 – 50 ℃
	Pressure	6 bar
	Analogic output	4 – 20 mA
	Digital output	RS485
	Power supply	9 – 36 VDC
 **Temperature sensor DS18B20**	Measuring range	-55 – 125 ℃
	Operating temperature	-5 – 50 ℃
	Digital output	1 Wire
	Power supply	3 – 5.5 VDC
 **Turbidity sensor SEN0189**	Measuring range	0 – 3000 NTU
	Operating temperature	5 – 90 ℃
	Response time	<500 ms
	Analogic output	0 – 4.5 V
	Digital output	High/Low
	Power supply	5 VDC
 **Flow sensor YFS201**	Measuring range	0.001 – 0.03 m^3/min
	Operating temperature	-25 – 80 ℃
	Pressure	17.5 bar
	Connection to process	½”
	Power supply	5 VDC
 **Ultrasonic sensor JSNSR04T**	Measuring range	20 – 600 cm
	Operating temperature	-20 – 70 ℃
	Response time	20 ms
	Output	Trig/Echo
	Power supply	3 – 5.5 VDC

Actuators

Based on the system characterization the following actuators were selected (Table 2) in order to maintain a constant water recirculation for the cycles established in the process sizing.

Table 2. Actuators selected for the automated aquaponic system

Actuator	Characteristic	Value
 **Submersible pump**	Power	750 W
	Maximum rate	300 l/h
	Output	1½"
	Maximum height	9 m
	Power supply	110– 220 VAC
 **Electro valve SENYA 2W-160-15**	Operating pressure	0 ~ 10 kg/cm3
	Operating temperature	-10 – 100 ℃
	Connection to process	½"
	Power supply	24 VDC

Controllers and HMI

Finally, the controllers (Table 3) are evaluated and selected to maintain the chosen variables within the established ranges.

Table 3. Selected controllers and HMIs for the automated aquaponic system

Controller/HMI	Characteristic	Value
	Power supply	24 VDC
	Digital inputs	14

 PLC Xinje XC3 24T	Digital outputs	10
	Input current	120 mA
	Maximum consumption	12 W
	Repsonse time (inputs)	10 ms
	Response time (outputs)	0.2 ms
	COM ports 1,2 and 3	RS232 and RS485
 Expansion module Xinje XC E4AD H	Power Supply	24 VDC
	Digital/analog inputs	4
	Input voltage	0 – 5 V, 0 – 10 V
	Input current	0 – 20 mA, 4 – 20 mA
 HMI Touchwin TG765ET	Power supply	24 VDC
	Input method	Touch
	Memory	128 MB
	USB ports	A and B
	COM ports	RS232 and Ethernet RJ45
	Operating temperature	0 – 50 ℃
 Arduino MEGA2560	Micro controller	ATmega2560
	Power supply	7 – 12 V
	Operating Voltage	5 V
	Digital/analog inputs	54 (15 de PWM)
	Analogic inputs	16
	Flash memory	256 KB
	EEPROM	4 KB

2.6. Node Design and Construction

With the selected instrumentation, a central node (medium cost) is designed and built for data acquisition and control of the actuators involved in the system, controlling the recirculation and oxygenation process. At the same time, a peripheral node (low-cost sensor network) is proposed, to be placed directly on the process, allowing the scalability of the solution and giving versatility when locating new nodes on the aquaponic system.

In this phase of the project, the electrical and electronic schematics of each of the modules (central and peripheral node) are generated along with the components required in the power stage, isolation, electrical and data connections, sensors, actuators and controllers.

Then, the construction and programming of a central node and a peripheral node is carried out for its subsequent calibration and implementation on the aquaponic system.

3. Results and discussion

3.1. Characteristics of the aquaponic system

A schematic of the aquaponic system was drawn up, identifying the different parts of the system:

Aquaponic system

Taking into account the characteristics of the aquaculture and NFT hydroponic subsystems, the final drawing representing the sizing of the aquaponic system was obtained (Figure 1).

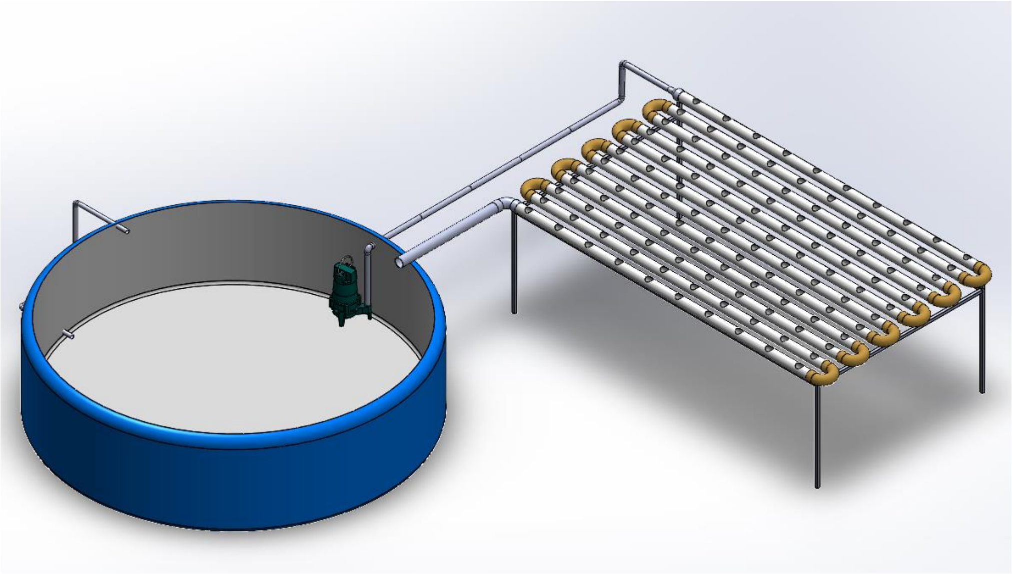


Figure 1. Aquaponic system SENA CBA.

The drawing shows the recirculation system driven by a submersible pump that carries water from the aquaculture tank to the NFT hydroponic piping network. The tank has its own oxygenation mechanism (at the back), using an external pump that by gravity injects water under pressure, generating bubbles as it falls back into the tank (described in materials and methods). On the other hand, and as a complement to the oxygenation system itself, there is an aeration tower on top of the tank, so that the water coming from a bifurcation in the recirculation pipes flows through the upper part of the tower and passes through perforated trays. Binding materials such as carbon coke, or plastic filler filter elements with a high area per volume ratio are used inside the trays.

Aquaculture system

Aquaculture system for fish breeding, with a 9 m³ cylindrical tank (external radius 1.5 m and internal height 0.72 m) Figure 2:

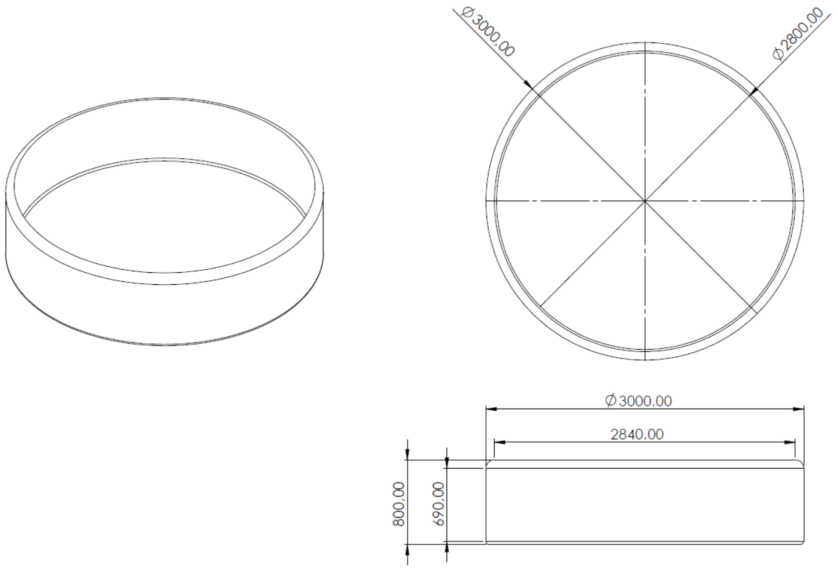


Figure 2. Hydroponic system SENA CBA.

In addition, one water pump is used to recirculate the water inside the tank, and a submersible pump (0.005 m³/min) distributes the water to the hydroponic system through a piping network. According to the fish species to be worked in the system, there will be a regime of seeding density, feeding, water exchange, oxygenation, and pH according to the established requirements.

Hydroponic system

Hydroponic system, consisting of a series of 3" pipes perforated with 50 mm diameter holes and spaced at 30 cm centers, which are capable of holding up to 120 plants, Figure 3.

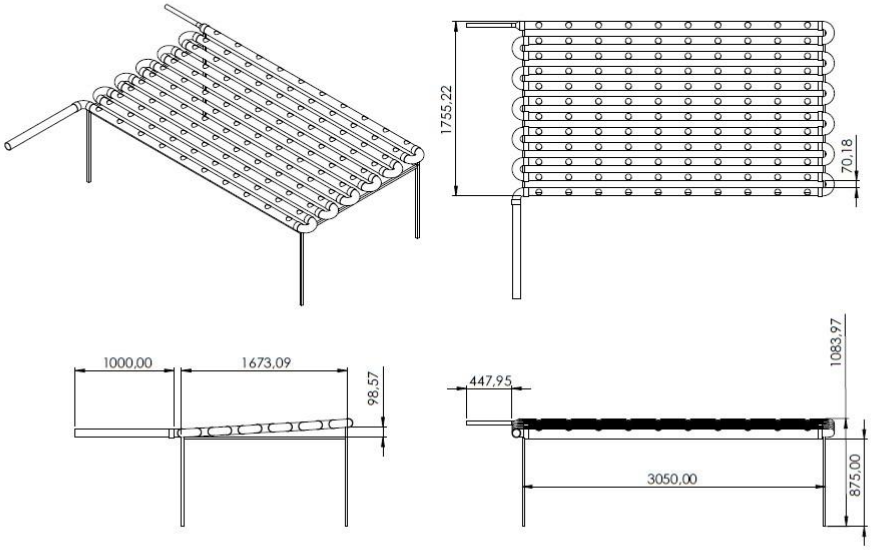


Figure 3. Hydroponic NFT system, piping network.

The NFT hydroponic piping system in series has an inclination that allows the constant flow of water, culminating its route back into the fish tank. Inside are foams, which serve the purpose of holding the seedling, in addition to retaining and absorbing fluids by capillarity, in this case the water coming from the aquaculture system.

Depending on the species to be cultivated and its phenological stage, the type of foam, the flow rates and the height of the water in the pipe may change.

3.2. P&ID Diagram

Previous scheme

Bearing in mind the data gathering on the structure, a P&ID diagram of the system is drawn in order to understand the distribution of the piping network, its connections and accessories (Figure 4) and thus propose a solution for instrumentation, monitoring and control.

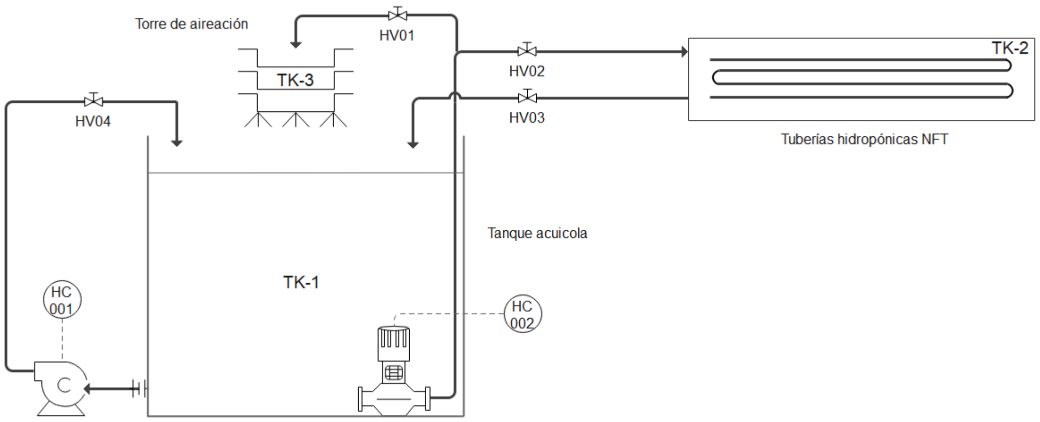


Figure 4. P&ID Diagram of the aquaponic system, SENA CBA.

In the diagram there are 3 main structures, the first one represents the aquaculture tank, the second one represents the hydroponic piping (arranged in this way to better visualize the inlet and outlet fittings to the NFT hydroponic sub-system) and the third one is identified as the aeration tower (composed of 3 perforated trays). Additionally, in the system there are two water pumps, a submersible one (in charge of the circulation from TK-1 to TK-2 and TK-3) located inside the tank, and an external one (own oxygenation system) together with its manual ball valve HV004, both operated by a worker by means of the push buttons HC001 (oxygenation pump) and HC002 (recirculation pump).

On the other hand, there are ball valves HV01 and HV02 (manually operated), that distribute the water flow to the aeration tower and the NFT hydroponic pipes, respectively. Finally, there is valve HV03, used to control the return flow from TK-2 to TK-1.

Proposed scheme

Based on the previous diagram, an updated P&ID is designed, including several sensors to monitor the critical variables in the system (identified by the characterization of the species to be worked), allowing to know the current status of the process and to control water replacement, recirculation and oxygenation cycles (Figure 5).

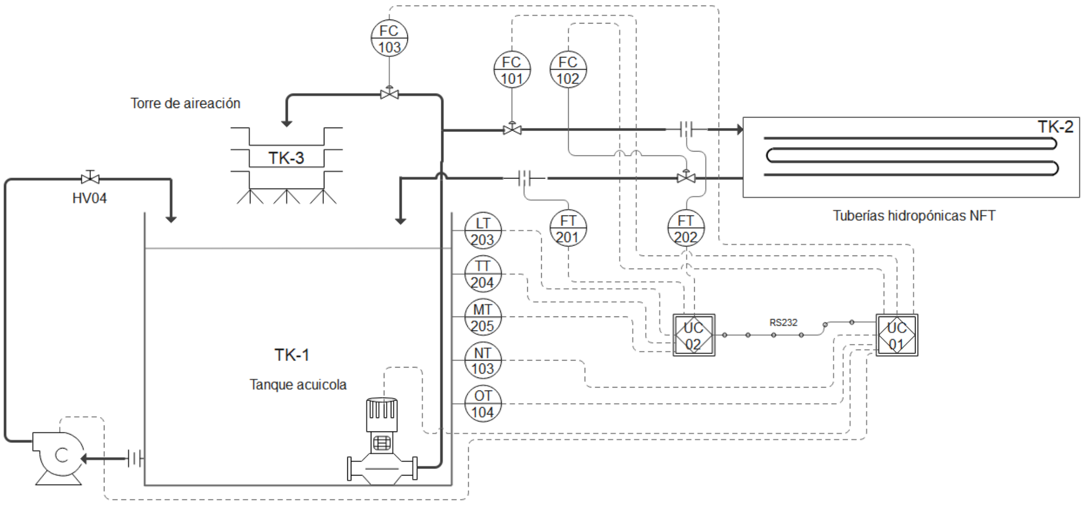


Figure 5. Proposed P&ID diagram for the aquaponic system, SENA CBA.

Manual controls of the pumps are initially replaced, now these are controlled by the central node UC01 (PLC Xinje), allowing to drive them as set in the program (also with manual control through a touch screen HMI in the central node).

In the recirculation system the manual ball valves are replaced by electro valves (FC101-103), allowing their actuation through the instructions given by UC01, also flow sensors (FT201-202) are added to know the amount of water entering and leaving the hydroponic pipes.

On the other hand, sensors to monitor dissolved oxygen (OT104) and pH (NT103) in the fish water are added in TK-1. Being high-cost sensors with HART protocol (communication through a 4-20mA current loop) these are connected to the central node to ease their reading and ensure their operation.

In parallel, the low-cost peripheral node UC02 (Arduino Mega) is responsible for acquiring the signals from the flow (FT201-202), level (LT203), temperature (TT204) and turbidity (MT205) sensors. This node collects the information and through an RS232 connection sends it to the central node, which will act according to the data received.

3.3. Design and construction of the central node

Based on the system dimensioning, crop characteristics and the P&ID, the central node is designed. In order to monitor and control the aquaponic system at the different spots identified, this prototype is built around a Xinje PLC and a Touchwin HMI screen, in charge of acquiring and displaying the relevant information for the operators (Figure 6).

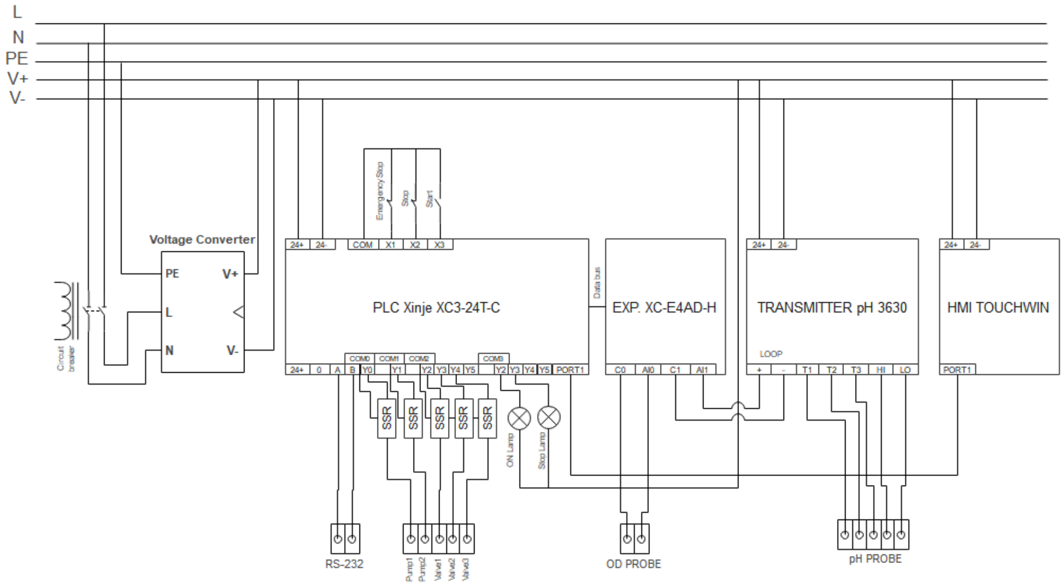


Figure 6. Electrical diagram of the central node.

As can be seen, the central node is powered by a fixed voltage source that converts 110VAC to 24VDC (protected by a two-pole breaker), which is responsible for supplying power to the PLC, its expansion module, the HMI and the pH transmitter.

The PLC has three push buttons (start, stop and emergency stop), that work to start, pause or stop the process, and two pilots (ON and Stop), that work to give visual alerts to the operators of the aquaponic system.

On the other hand, it has five solid state relay (SSR) outputs, two of them to drive the water pumps and the other three to control the recirculation and oxygenation electrovalves.

In conjunction with the expansion module for analog inputs, the PLC is able to obtain data from signals under HART protocol (0-20 or 4-20mA and 0-5V or 0-10V). With this in mind, a dissolved oxygen probe (able to deliver the standard signal directly) and a pH transmitter (which acquires, converts and transmits the values recorded by the probe) are adapted.

Finally, an input for RS-232 communication is used to connect it to the peripheral nodes.

From the specified drawings, the construction of the central node is carried out, for this purpose all the required elements are placed in a dust and humidity protection cabinet (IP62), Figure 7.

(a) (b) (c)

Figure 7. (a) Frontal view of the central node; (b) Back view of the central node door; (c) Internal view of the central node.

In the front view of the cabinet, on the top area is the touch screen HMI, used to display relevant information to the user and to control each of the process actuators.

Below the screen are the two warning lights, the green one indicating a normal process flow and the red one to notify about failures or events that require an operator to be resolved (e.g., deficiencies in pH values, dissolved oxygen, water levels, among others). Finally, there are three push buttons (start, stop and emergency stop) performing the functions described in the previous section.

Inside the cabinet (Figure 7b and 7c), the front view elements (and their wiring) can be seen, while in the upper right zone the two-pole breaker, the power supply and the pH transmitter can be seen; below are the PLC and its expansion module; and at the bottom are all the terminal blocks and relays for the inputs and outputs described in the electrical drawing (together with a series of cable glands to ensure the integrity of the wiring and the cabinet).

Programing and interface of the central node

For the programming of the Xinje controller, a Grafcet diagram was initially designed (Figure 8), its programming is generated in Ladder language.

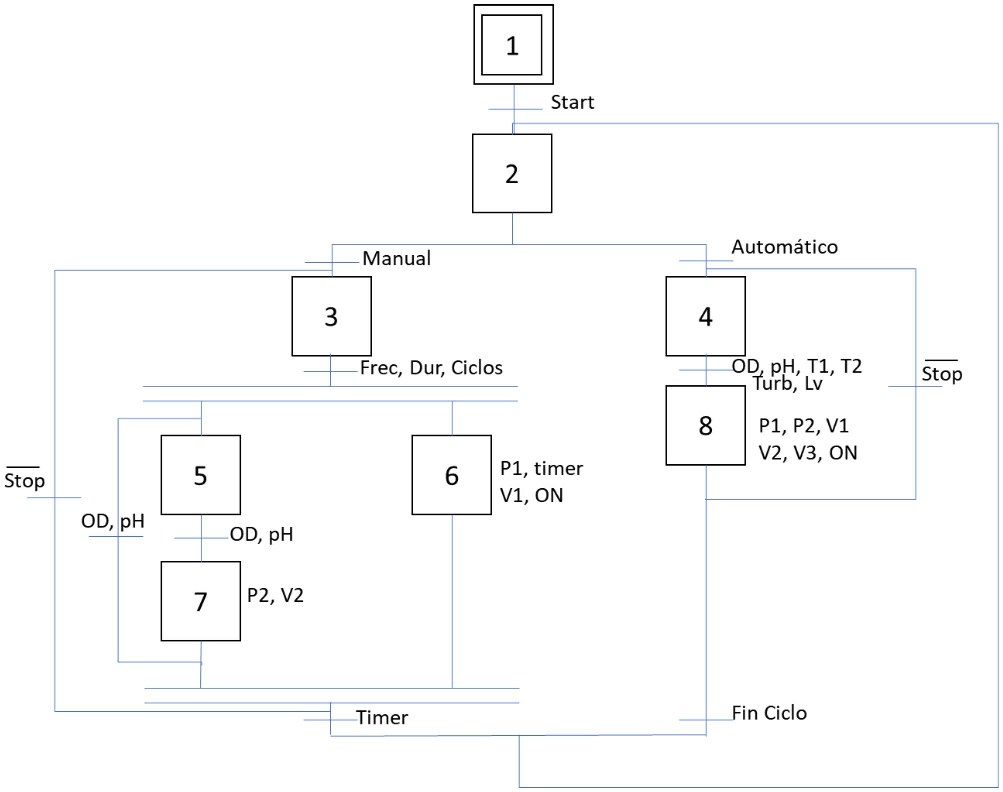
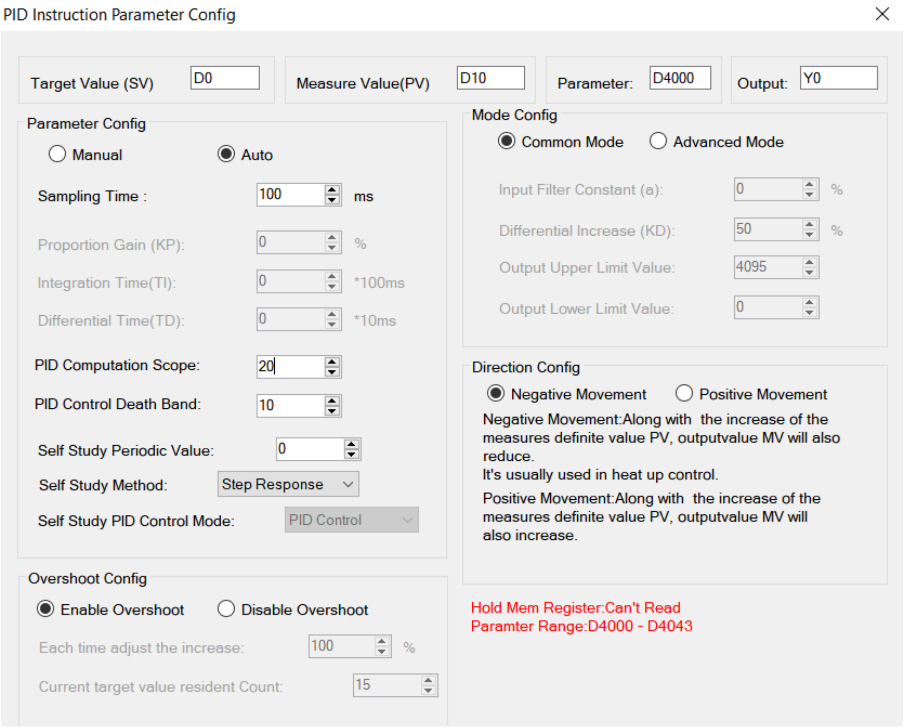


Figure 8. Grafcet of the control program.

The program starts with standby state 1, waiting for the start button to be pressed to trigger the initiation of the process. Subsequently, state 2 waits for the selection of the operating mode, in this case manual or automatic. Once one of the modes is selected, the corresponding cycle is executed.

In manual operation, the system enters state 3, where the user can select the desired frequency, duration and number of recirculation cycles. For this purpose, there is a dialog box in the interface where the weekly and daily cycles are entered, as well as the length of the water flow in hours and minutes. Depending on the information entered, the system will process and calculate a timer that will define the total duration time of state 6, activating and deactivating pump 1, valve 1 and the green ON pilot light. Simultaneously the cycle of states 5 and 6 is executed, whose function is to evaluate the DO and pH levels to activate pump 1 (internal recirculation), and valve 2 of the oxygenation tower.

On the other hand, if the automatic mode is selected, the controller performs a preliminary measurement (state 7) to determine the current values of DO, pH, temperature, turbidity and level, to achieve this a PID block is integrated (Figure 9) with auto tune functionalities, where a preliminary measurement is made and the controller itself is responsible for optimizing the control according to the established ranges.



PID Instruction Parameter Config

Target Value (SV): D0
Measure Value(PV): D10
Parameter: D4000
Output: Y0

Parameter Config
○ Manual ● Auto
Sampling Time : 100 ms
Proportion Gain (KP): 0 %
Integration Time(TI): 0 *100ms
Differential Time(TD): 0 *10ms
PID Computation Scope: 20
PID Control Death Band: 10
Self Study Periodic Value: 0
Self Study Method: Step Response
Self Study PID Control Mode: PID Control

Mode Config
● Common Mode ○ Advanced Mode
Input Filter Constant (a): 0 %
Differential Increase (KD): 50 %
Output Upper Limit Value: 4095
Output Lower Limit Value: 0

Direction Config
● Negative Movement ○ Positive Movement
Negative Movement:Along with the increase of the measures definite value PV, outputvalue MV will also reduce.
It's usually used in heat up control.
Positive Movement:Along with the increase of the measures definite value PV, outputvalue MV will also increase.

Overshoot Config
● Enable Overshoot ○ Disable Overshoot
Each time adjust the increase: 100 %
Current target value resident Count: 15

Hold Mem Register:Can't Read
Paramter Range:D4000 - D4043

Figure 9. Xinje controller PID block.

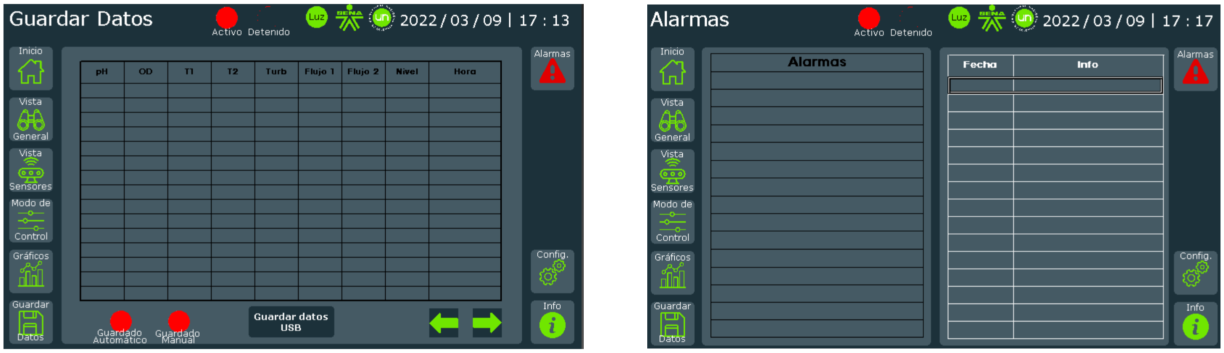
From the established ranges in the program and comparing them with the measured ones, the system acts to maintain the variables stable, using pumps 1 and 2 and valves 1, 2 and 3, in the manual mode the recirculation cycles are not taken into account, so it prioritizes the control of the dissolved oxygen and hydrogen potential variables.

At the end of the timer of the manual cycle, or when pressing the end of cycle of the automatic mode, the system returns to state 2 to start a new cultivation process, also in each of the modes there is a stop function that allows to stop the outputs and reset the process to its initial states.

The graphical interface of the HMI has a main menu where each of the screens that the user can access can be observed (Figure 10a).

(a)
(b)
(c)
(d)

(e) (f)



(g) (h)

Figure 10. (a) Main screen; (b) General view; (c) Sensor view; (d) Manual control; (e) Cycle control; (f) Graphs; (g) Save data; (h) Alarms.

Additionally, an overview screen is programmed (Figure 10b) where the user can see the piping configuration, the direction of the water flows, the current status (on or off) of each of the system actuators and the real-time values of the measured variables.

In the sensor view (Figure 10c) different scales were implemented in order to see the optimal, alarm and emergency ranges, indicating in what cases the user must act immediately (throwing pop-ups as an alarm).

In the manual control view (Figure 10d) the user can turn on or off the different actuators, as well as program the frequency and duration of the recirculation cycles (Figure 2-10e) (changing them according to the current state of growth of both plants and fish).

Finally, there is the graph screen (Figure 10f) where it is possible to observe the trend line of each of the measured variables, also allowing to store all the information in the PLC registers or in a USB memory stick thanks to the Save Data button.

In the save data screen (Figure 10g) a table with the organized information of each of the sensors is observed, in addition to the time at which the corresponding value was recorded. In order to export the information, the screen has an automatic save that every 30 seconds fills a csv file in which each iteration appends a new row. On the other hand, it has a manual export button that allows sending all the data visible in the table to a new file.

In addition, it has three pop-ups (on the right side) that provide information on the alarms produced throughout the system operation (Figure 10h), a light and tone configuration of the screen and a dedicated button where a QR code can be consulted that will take the user to the documentation (plans, diagrams and programs) concerning the automated aquaponics project.

3.4. Design and construction of the peripheral node

Unlike the central node, the planning, design and construction of the peripheral node were intended to be low-cost, taking into account the modularity of the system, making it easier to expand the system and allowing new nodes to be added if required by the user. The peripheral node constantly sends information to the central node, for this reason it does not include a screen or interface to interact with the user (Figure 11).

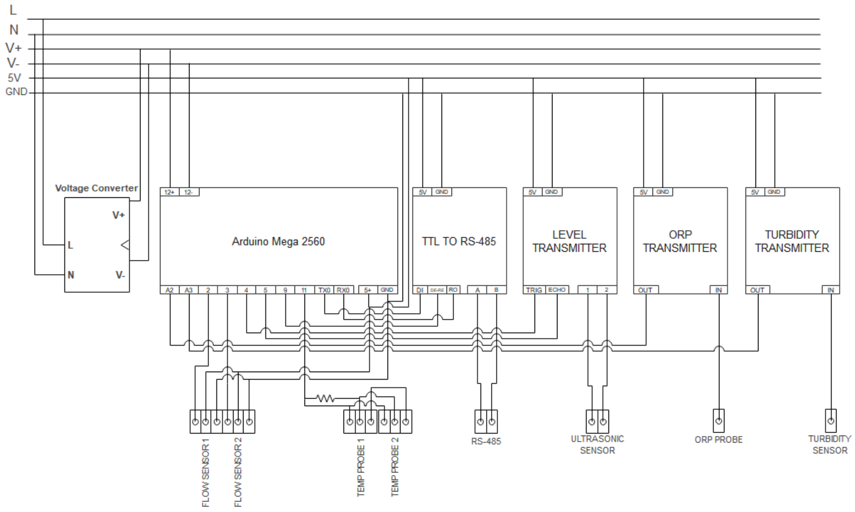


Figure 11. Electrical diagram of the peripheral node.

The peripheral node is built around an Arduino Mega as controller, a voltage adapter for its power supply, a TTL to RS-485 serial converter for communication with the central node and three level, ORP and turbidity transmitters that take the signals from their respective probes. On the other hand, it has two hall effect flow sensors and two temperature probes (submersible), which do not require conversion modules.

This node only acquires and transmits the signals of the variables selected in the P&ID diagram, for this reason it does not include any type of relay or transistor for output control, a task delegated to the central node.

Taking into account the electrical diagram, the dimensions of the integrated circuits and their corresponding wiring, the construction of the peripheral node is carried out, Figure 12. Each of the elements is fitted inside a housing with IP61 protection, resistant to dust and liquid splashes, with 4 cable glands for the input and output of the sensor, power and communication cables.

Figure 12. Internal view of the peripheral node.

In the upper left corner, there are the real-time clock (RTC) and TTL to RS-485 communication cards, in the central region there is the Arduino Mega 2560 together with a distribution strip for the power supply lines and in the upper right corner there are the signal conversion modules for the ORP, turbidity and ultrasound sensors. Under the conversion cards is distributed a region for the connection of each of the probes and sensors, providing easy access and allowing greater organization inside the node.

Programing and interface of the peripheric node

The peripheral node program was written with the Arduino program, therefore, due to its functionality it includes the libraries and codes provided by the manufacturers for the reading of each of the selected sensors.

In addition to the normal code, the open-source MODBUS RTU communication library is added, which allows assigning a series of registers which will be receiving the information from each of the sensors in real time, these registers can be consulted by the central node through the MODBUS RTU 06H function, all data are processed and displayed on the HMI interface.

Data acquisition results

pH

For the first test, a daily pH graph was generated (Figure 13), showing that the lowest values are found between 00:00 h and 06:00 h, while the highest values are found between 12:00 h and 18:00 h.

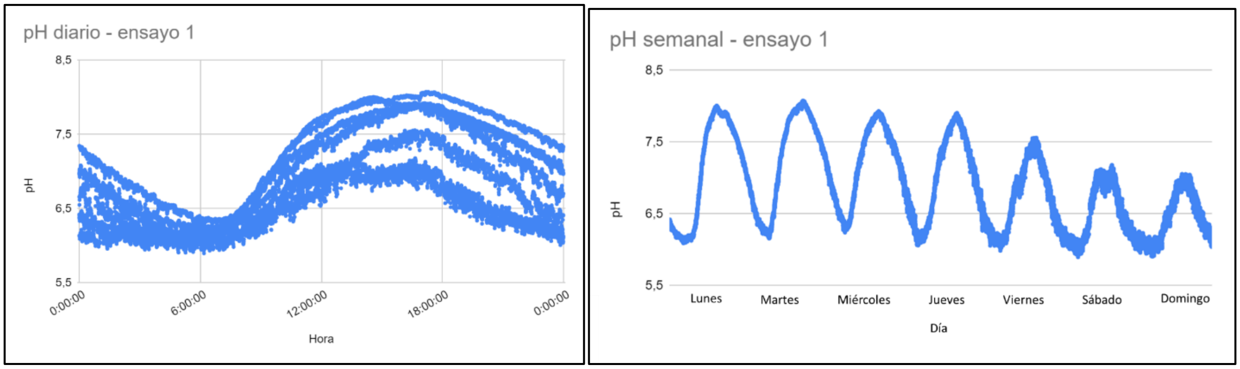


Figure 13. Daily pH 1 and Weekly pH– test 1

In addition, special emphasis is placed on the maximum peaks that reach values up to 8.01 and the minimum peaks that are around 5.8.

Taking into account the reports of [36] and [37] the average values calculated for both tests, a graph is generated (Figure 14) where it can be noted that 59.2% of the pH values are in accordance with those admissible for fish welfare (between 6 and 8) and nitrifying bacteria (between 5.5 and 7).

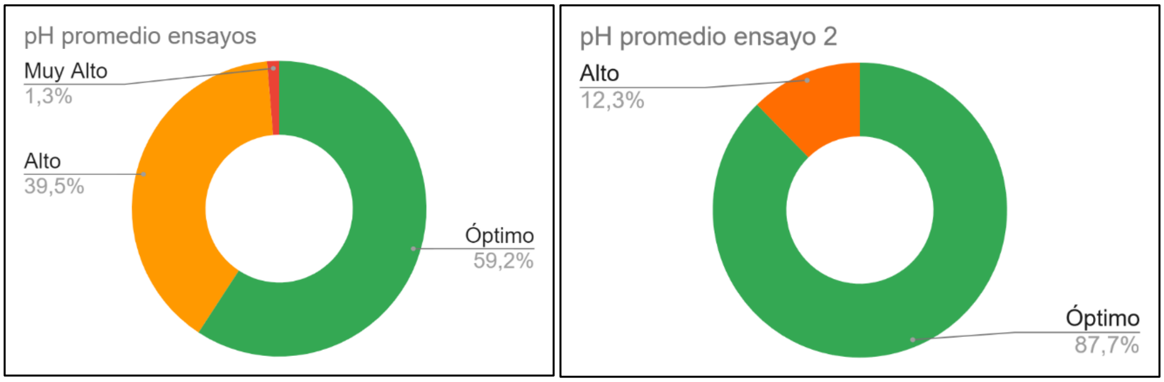


Figure 14. Percentage distribution in pH ranges

Although in the case of plants, which are less tolerant (between 6 and 7), alkalinity stress is perceived in 40.8% of the pH values, which translates into difficulty in dissolving compounds such as calcium, iron and phosphorus [38], in addition to producing an increase in the decomposition of organic substances that in the long term generate accumulation of unwanted biomass in the piping systems, as could be observed throughout the tests.

Disolved Oxigen

For the first test, a graph of daily dissolved oxygen was generated (Figure 16), and the values were found to range from 3.5 ppm to 5.9 ppm.

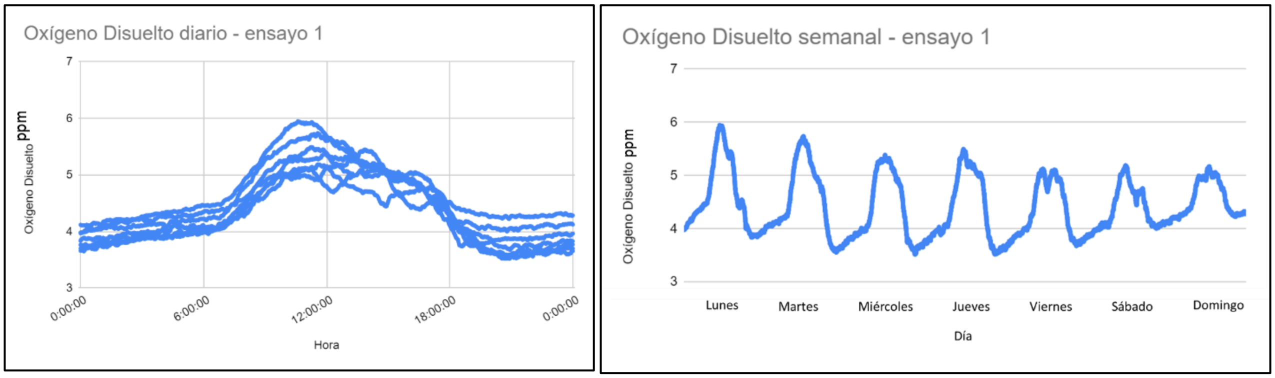


Figure 16. Daily dissolved oxygen and Weekly dissolved oxygen - test 1

It can also be seen that an increase in the production of dissolved oxygen occurs in the time period from 09:00 h to 17:00 h.

For both tests, values within the optimal range (Figure 18) for the productivity of fish, plants and bacteria [37] were found to be 79.8%. Although high peaks exceeding the nominal values, corresponding to 20.2%, are noticed, the duration of these peaks does not produce a serious impact on biomass generation (mainly for plant species), as shown in their study [38].

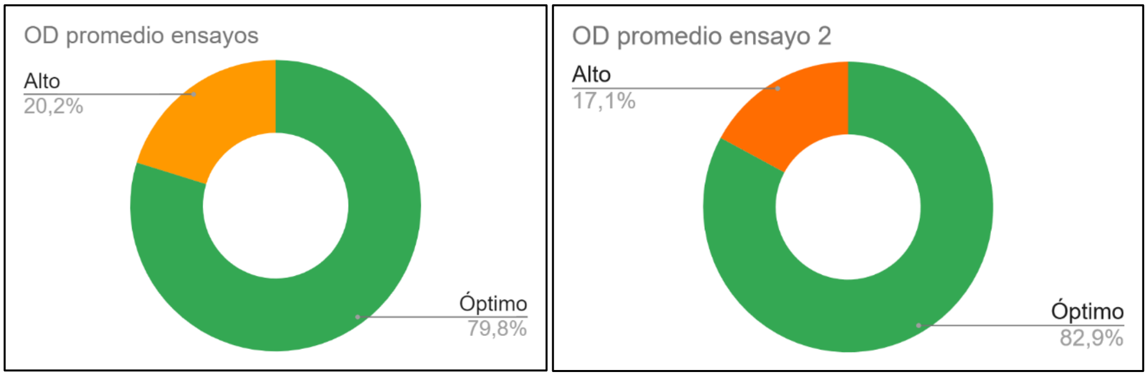


Figure 18. Percentage distribution in dissolved oxygen ranges

According to reports by [39] and comparing it with the results obtained, one of the main causes of the increase in dissolved oxygen productivity (in the identified strips) is due to phytoplankton, its photosynthesis and the relationship with the amount and intensity of photosynthetically available light, which, although in large ponds decreases with water depth as reported by [40], in the case of the structure used for these tests does not represent a critical factor.

Temperature

In the case of temperature, it was measured at two points in the tank in order to obtain a representative measurement. Figures 19 and 20 show the daily temperature for sensors T1 and T2 in test 1, showing the homogeneity with respect to its distribution.

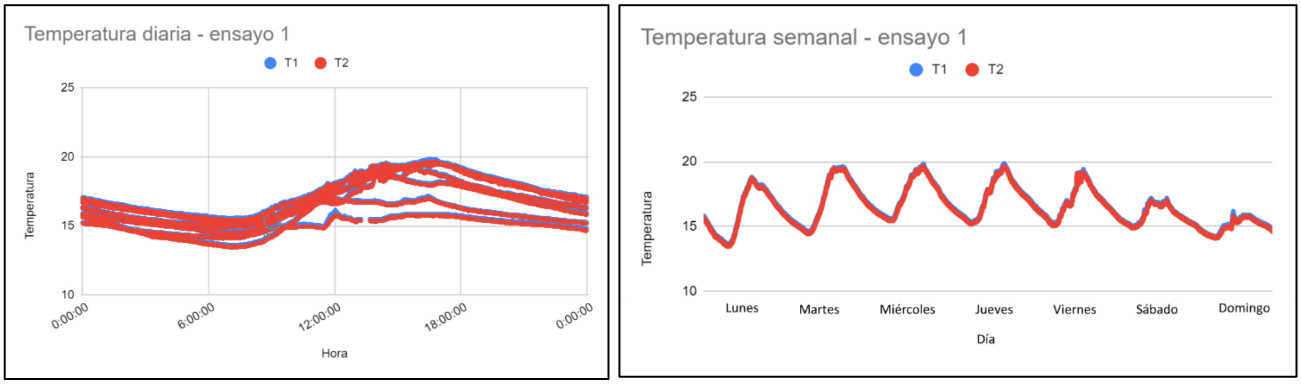


Figure 19. Daily temperature and Weekly temperature - test 1

In addition, two important bands are identified, one between 00:00 h and 07:00 h where the lowest values are recorded, and the other between 11:00 h and 17:00 h, which represents the warmest hours in the water.

5. Conclusions

In order to carry out the design and construction of the automated system over a traditional system, it is necessary to proceed with an adequate data gathering, including a dimensioning that describes the characteristics of the aquatic and plant species to be cultivated, identifying the optimal ranges. Carrying out these tasks allows the selection of sensors, actuators and controllers to be simpler but also adequate and objective.

When performing the operating modes of the nodes, and in general the programming of the control system and its interface, it is important to take into account that users can interact in a simple way, with basic functions that they can learn and execute, so it is recommended a comprehensive approach with users working with the nodes, both central and peripheral.

Although the selection of elements such as sensors, actuators and controllers were adequate, the communication protocols may limit and interfere with the transmission of information, which is why in some cases there may be delays in the real-time display of variables and even lose values.

The proposal is based on the application of low and medium cost technologies in order to make it attractive to new users who wish to apply new tools in their crops, for this reason it was designed to be modular, expandable through inexpensive peripheral nodes. Although this is possible, it is recommended to apply different communication methods such as WiFi, GPRS or LoRa that allow a much more adequate scalability and can be adapted to different terrains and territories.

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