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A Case-study vision

Automation of the recirculating water system of an aquaponic crop

Automatización del sistema de recirculación de agua de un cultivo acuapónico

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ABSTRACT

This article is the product of the research project entitled "Standard architecture design for the acquisition and transmission of data integrated in the automation of aquaponic crops", exposes the design and implementation of the automation of the reading, storage and transmission processes of data. Water quality parameters in a prototype aquaponic culture, made up of tilapia fish and short-cycle aromatic plants. The process of evolution of the variables ammonia, nitrate and pH is modeled through the Matlab Simulink tool and the historical values carried out in the field by IoT devices are recorded. It is possible to obtain the validation of the architecture of the required hardware and the dimensioning of the components of the solution in an integral way, projecting its applicability and sustainable contributions for the activity of aquaponic production in Colombia.

RESUMEN

El presente artículo es producto del proyecto de investigación titulado "Diseño de arquitectura estándar para la adquisición y transmisión de datos integrados en la automatización de cultivos acuaponicos", expone el diseño e implementación de la automatización de los procesos de lectura, almacenamiento y transmisión de los parámetros de calidad del agua en un prototipo de cultivo acuapónico, conformado por peces tilapias y plantas aromáticas de ciclo corto. Se modela el proceso de evolución de las variables amoniaco, nitrato y pH, a través de la herramienta Simulink de Matlab y se registran los valores históricos realizados en campo por dispositivos IoT. Se logra obtener, la validación de la arquitectura del hardware requerido y el dimensionamiento de los componentes de la solución de forma integral, proyectando su aplicabilidad y aportes de tipo sustentable para la actividad de producción acuapónica en Colombia.

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1. Introduction

The transition to a world with food security requires the contribution of new technological and organizational paradigms that engineering and other fields of knowledge can bring together[1], capable of being integrally compatible both in their objectives, interests and organizational structure with a projection capable of establishing new methodologies and trends in production, marketing and innovation with an added value in nutritional matters, which contribute to the health and welfare of human beings[2]. One option capable of contributing to this necessary transition is represented by aquaponics, according to[3], an aquaponic system integrates a fish culture and a plant culture, in a symbiotic way, thanks to the fact that the fish waste feeds the plants, which in turn clean the water of the culture, making an efficient use of the nitrogen cycle and also avoiding the replacement of the water in the culture pond for long periods of time[4] the high potential of aquaponics is demonstrated, due to its ability to achieve nitrogen recovery from aquaculture wastewater, by reducing nitrates by assimilating nitrogen in organic vegetables and plants. As stated in[5], aquaponics has been gaining ground in the last 5 years, due to its efficient use of water, without polluting it.

The projection of the paradigm shift continues thanks to the contribution of the fourth industrial revolution or industry 4.0, among which we can find: the transformation and modernization of production methods, work, the way society relates, the generation of new products and the support of new services, which leads to the emergence of new needs in terms of knowledge [6]. Advances in information and communication technologies have been adapted and applied expanding the context of intelligent production systems known as Smart arms, with the purpose of obtaining data through sensors for monitoring and controlling them remotely with the use of wireless networks [7]. In terms of developments generated from information technologies and IoT, applied to the automation of projects related to the agricultural sector, we find that these have been used in the definition of smart farm infrastructures that allow to support all its processes [8], monitoring and analysis of climate variables for precision agriculture [9], storage and visualization of massive data for variables in greenhouses [10].

On the other hand, research developments involving aquaponic production systems have dealt with various aspects and have been going on for several years. In [11] the technique of multiparametric measurement of crop variables is exposed, the results and benefits of doing so using electronic devices versus measurements with manual techniques are contrasted. The document is structured in three sections, the first one corresponds to the methods and materials used; the second section is dedicated to the analysis of results; and the third section to the conclusions obtained.

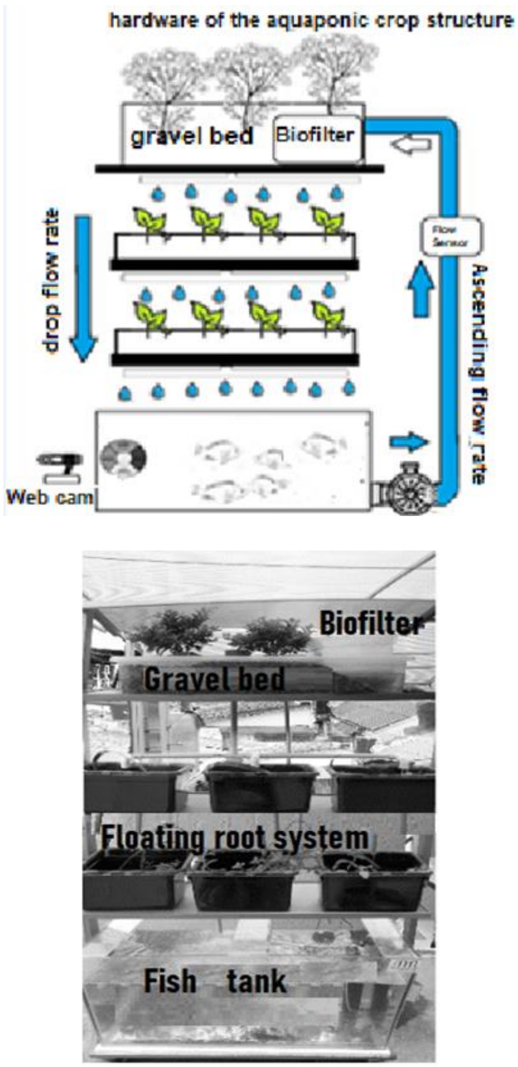
2. Methodology

For this research, 2 important aspects were considered for its development: the first is the required instrumentation and the architecture of the prototype, which is integrated by the IoT elements, used for the processes of reading, recording and transmission of the variables of the water quality parameters in the crop, which are stored locally in physical form, with the possibility of being exported to a database in the cloud. The second component of the research refers to a mathematical model, used to predict the possible values of the variables and their behavior in an established period, which allows us to dimension the quotas of the variables to be taken into account, in order to avoid the intoxication of the fish in the culture by excessive levels of ammonium or nitrate, as well as an abrupt change in the pH of the pond water.

2.1 Prototype of aquaponic culture used

The structure of the aquaponic culture prototype is shown in Figure 1, designed and constructed by[12], It consists of a vertical distribution of 4 levels, in the lowest level there is a fish pond, from where the water containing the fish waste is pumped, the water reaches the biofilter located in the highest or upper level, There, impurities are captured and the bacteria carried by the water are nitrified. The gravel bed is planted with short production cycle plants, which are flooded as their level rises, to be emptied thanks to the action of a bell type siphon, which pours the water to level 3 of the culture, The process is repeated at level 2 of the system, generating a downward flow that oxygenates the fish tank and decreases its temperature by convection, thus ensuring the survival conditions of the fish, while the plants are nourished with fish waste, this process is constantly repeated, constituting an automated Water Recirculation System (SAR).

Figure 1. Details of the architecture of the aquaponic culture prototype used



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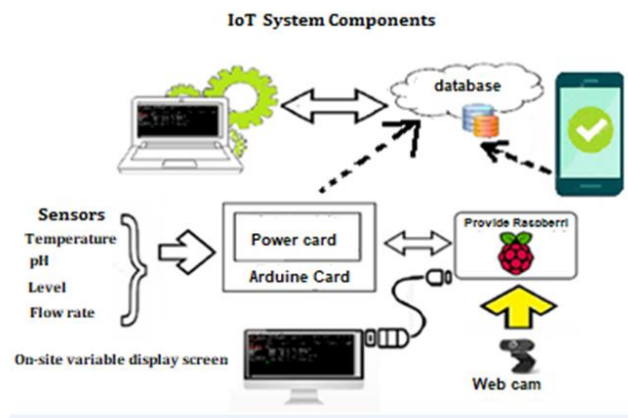
As for the IoT elements of the system, we can see them in figure 2, these are made up of a series of sensors, which are strategically placed in the fish pond to measure: Temperature, pH, water level and its upstream flow, the signals from these 4 sensors are connected to an interface card and then to the input ports of an Arduino Atmega card, which concatenates them into a vector and sends to the Raspberry pi card via USB port, To measure the combined nitrate and ammonium levels in the fish pond, first a picture is taken of the center of an indicator disk attached to the glass wall of the fish pond with the webcam, this picture is taken to the Raspberry pi board via USB port, where a digital image processing algorithm is run to identify the color of the disc, translating it into a numerical value that indicates the amount of parts per million of ammonium and nitrate combined in the fish pond, this value is concatenated in the Raspberry pi with the vector of the other 4 variables delivered by the Arduino Atmega, to then be transmitted via wifi to a database set up to store the information, from where it can be accessed to graphically monitor the variables of the aquaponic system, you can also view these values by connecting a monitor via USB to the port of the Raspberry pi. The process of reading, transmission and storage of the information is constantly repeated, thus providing the advantage of knowing the behavior of the water quality parameters, an essential factor for the production of an aquaponic crop.

Figure 2. Details of the IoT architecture used for sensing.



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2.2 System Modeling

In the next phase, a simulation model of the system was established in order to estimate the response of the aquaponic culture with respect to three critical factors for fish survival, namely: ammonia concentration in the culture bed, ammonia concentration in the water tank and nitrate concentration in the culture bed.

The construction of the model follows the equations (1) to (15) given by [13] which allow establishing the growth dynamics of both plants and fish, the rates of change of ammonia (NH3) and nitrate (NH4O3) and the changes in water pH.

In the first instance we calculate the ammonia exchanged by tap water, this can be done with equation (1).

$$\Delta \mathrm{NH3}_C = \mathrm{MNH3}_T(t-1) - \mathrm{MNH3}_C(t-1) * Q \qquad (1)$$

∴ $\Delta NH3_C$=delta Ammonia in the culture bed

$MNH3_T(t-1)$ = Ammonia concentration in the water tank (t - 1)

$MNH3_C(t-1)$= ammonia concentration in the culture bed (t - 1))

Q= Water flow rate;

By interrupting the water flow in the culture, the amount of ammonia in the vessel is only changed by the interaction between fish and plants, as evidenced by equations (2) and (3).

$$\Delta NH3_T = \Delta NH3_T + QNH3_P \quad (2)$$

$$\Delta NH3_C = \Delta NH3_T + CNH3_m \quad (3)$$

∴ $\Delta NH3_T$=delta Ammonia in water tank.

$QNH3_P$ =Ammonia production rate per fish (i)

$CNH3_m$=Ammonia consumption rate per microbe

Through equations (4) and (5), we can update the volume of water present in the tank and the culture bed, in which the effect of water evaporation is considered.

$$V_{lc} = V_{lc} - (temp * 0.001) \quad (4)$$

$$V_T = V_T - (temp * 0.001) \quad (5)$$

∴ $V_{lc=}$ Volume of the growth bed

V_T = Volume of the water tank; $temp$ =temperature * 0.001

The growth of fish and plants can be followed with equations (6) and (7), with which their growth rates can be updated.

$$P_{p=}P_{pn} * (1 - 0.01 * V(pH_T - pH_n) * p_t pH)) \quad (6)$$

$$P_{c=}P_{cn} * (1 - 0.01 * V(pH_c - pH_n) * p_t pH) \quad (7)$$

∴ $P_{p=}$ Fish growth rate

P_{pn} = Normal fish growth rate

$V(pH_T)$ = Absolute value (pH in water tank - normal pH)

$p_t pH$ = PH influence growth rate factor

$P_{c=}$ Plant growth rate

P_{cn} = Normal plant growth rate

$V(pH_c)$ = Absolute value (pH in the culture bed)

To follow the rate of ammonia consumption per microbe present in the culture, we use equation (8)

$$PNH3_{m=}PNH3_{mi} * (1 - 0.01 * V(pH_c - pH_n) * p_t pH) \quad (8)$$

∴ $PNH3_{m=}$ Ammonia consumption rate per microbe

$PNH3_{mi}$ = Initial ammonia consumption rate per

The ammonia concentration in the fish tank is established by equation (9).

$$MNH3_T(t) = \frac{(MNH3_T(t-1) + \Delta NH3_T)}{V_T} \quad (9)$$

∴ $MNH3_T(t)$ = Ammonia concentration in the water tank (t)

Updating the nitrate concentration in the growing beds is done through equation (10).

$$MNH4O3_C(t) = MNH4O3_C(t-1) + (\Delta NH3_{C*}NH3_{NH4O3}) + (N_P * CNH4O3_p) \quad (10)$$

∴ $MNH4O3_C(t)$ = Nitrate concentration in the culture bed (t)

$MNH4O3_C(t-1)$ = nitrate concentration in the culture bed (t - 1)

$\Delta NH3_{C*}$ = delta Ammonia in the culture bed; $NH3_{NH4O3}$ = ammonia to nitrate rate

N_P = Numbers of Plants ; $CNH4O3_p$ = Nitrate consumption rate per plant;

The evolution of fish and plant numbers is performed using equations (11) and (12), respectively.

$$N_p = N_p * (1 + P_p) \quad (11)$$

$$N_P = N_P * (1 + P_c) \quad (12)$$

The concentration of ammonia and nitrate in the culture bed are established with equations (13) and (14), respectively.

$$MNH3_C(t) = \frac{MNH3_{Ci}}{V_{lc}} \quad (13)$$

$$MNH4O3_c(\mathrm{t}) = \frac{MNH4O3_{Ci}}{Vl_{cm}} \quad (14)$$

∴ $\mathrm{MNH3}_{Ci}$ = initial amount of ammonia in the culture bed

$MNH4O3_{Ci}$ = initial amount of nitrate in the culture

The concentration of ammonia in the water tank is determined from equation (15)

$$\mathrm{MNH3}_T(\mathrm{t}) = \frac{\mathrm{MNH3}_{Ti}}{V_T} \quad (15)$$

∴ $\mathrm{MNH3}_{Ti}$= initial amount of ammonia in the water tank

Table 1. Values considered for modeling aquaponic cultivation.

Simulation parameter for model validation		
Input parameter	**Value**	**Unit**
Crop tank water volume (VT)	200	Liters
Volume of water for crop beds (VC)	80	Liters
Number of fish (Np)	50	Fish
Short-cycle plants for cultivation (NP)	70	Plants
Measuring time (time)	30	hours
Normal growth rate for fish	0.00003	cm/day
Constants considered in model equations		
Species-specific factors	**Value**	**Unit**
pH influence growth rate factor	2	mm / day
pH influence reaction factor	2	--
Pumping flow rate	3.5	Liters/ Minute
Maximum NH3 production rate	0.01	mg/ hour
Minimum NH3 production rate	0.02	mg/ hour

Source: Adapted from. [13] For tilapia fish and aromatic plants.

Equations (1) to (15) are integrated to the model built using the Simulink tool of Matlab.

The simulation parameters of the model are entered by console, through the Matlab command window, for which the input parameters were considered to be those established by the characteristics of the prototype described in Figure 1 and the factors of the tilapia fish species established by[14] and listed in Table 1.

3. Results and discussion

The results of the project have an impact on the environment, as its contribution to the development of a new food production technique with an efficient use of water, as demonstrated by the technological impact of the monitoring tool designed here, can contribute to closing the gap in access to the advantages of IoT, existing between large and small producers.

Figure 3a illustrates the curves obtained in the process of measuring ammonia for 120 hours in the culture bed and the simulation of the same parameter using the implemented model.

Figure 3. a) Logging curves for ammonia in culture bed b) Logging curves for ammonia in fish water tank c) Nitrate concentration in culture.

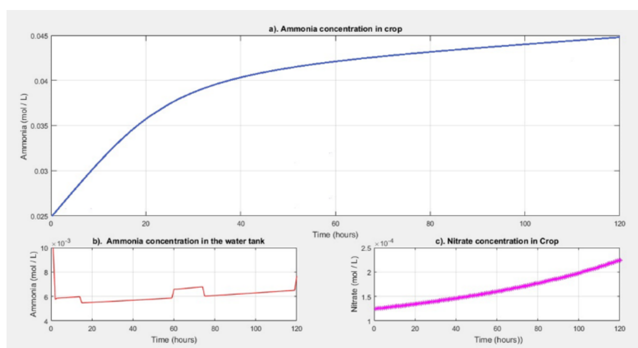

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Figure 3b allows observing the ammonia concentration records in the fish water tank, thanks to the simulation we will have a very valuable estimate of the trend of this important water quality parameter and finally, figure 3c shows Nitrate concentration in crop.

The concentration of nitrate in the culture bed is illustrated in figure 4a, during a period of 120 hours it was possible to verify the correct and uninterrupted recording of this variable, in the mathematical model the feeding of the fish is considered as a periodic cycle, a situation that is somewhat distant from reality, it is considered this way for theoretical purposes of experimentation.

Figure 4. a) Log curves for nitrate concentration in the culture bed

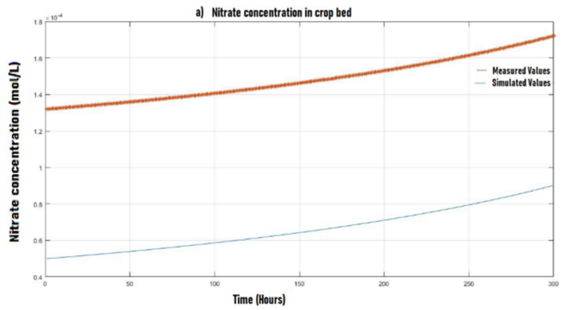

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Figure 4. b) Log curves for water pH in the culture bed

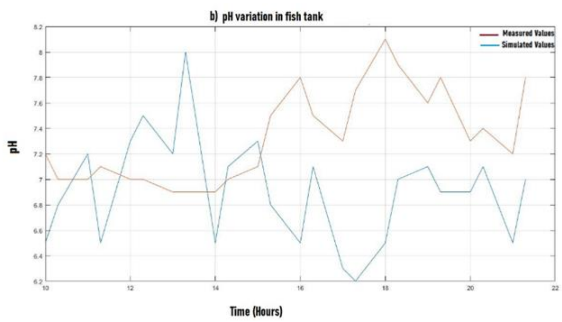

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Figure 4b describes the behavior of the pH of the water in the fish tank, the measuring instrument remained constantly submerged during the 13 hours of the procedure, the differences between the behavior of the real excretion phenomenon of the fish and that simulated by the model, influenced the difference reported between the values recorded for the measurement and simulation of this variable, however, the two curves record the same trend of behavior for this variable.

4. Conclusions

The modeling component incorporated into the platform is an important complement to the automation of the processes of reading, storage and transmission of crop water quality parameters, which considers the dynamic behavior of the feeding and growth of the two crop species. This technique proved to be able to anticipate the evolution of these parameters, with reduced differences with respect to the measurements made by the IoT devices installed in the field.

The architecture obtained allows you to offer a variety of services to your users, and thanks to its cloud-based layout, you will be able to take into account the particular situations of your end users, along with future changes in the technology of the devices used.

In perspective of future research works, there are experiences dealing with the use of IoT devices to wirelessly measure multiple parameters in network and in real time [7], in order to increase the scientific production related to the usability criteria in the developments offered by information and communication technologies[15], together with the need to establish manageable, centralized and dynamic networks, such as software-defined networks (SDN)[16], work on defending against attacks, identifying security vulnerabilities in operating systems and wireless security protocols[17].

In another line of research, advances have been made in connecting crops to a database and visualizing the information in the cloud[11-12], [14], [27-29], flexible architectures with computer vision[19], implementation of high quality sensors and calibration to decrease false machine stop times[20], technological reconversion in the production plant, aiming at improving productivity by reducing production times, increasing product quality and reducing costs[21]. All of them incorporate IoT technology with scopes referred to reading processes during short periods, unlike the architecture presented here that allows permanent monitoring throughout the day.

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