Modeling And Design Of A Level And Ph Control System Using Pid Algorithm To Optimize Water Quality In Aquariums

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ABSTRACT

The present project promotes one efficient technique to grow aquatic species. Our project uses the mathematic model of a pond, PID's control theory and ON/OFF control to make a control of two variables. First, the pH's measurements allow the second control. Second, the control consists in a PID control over water level. When the pH and water level are at regulated levels, the PID control will be deactivated.

Keywords:*mathematic model, PID, aquatic species, pH*

Article Received: 18 October 2020, Revised: 3 November 2020, Accepted: 24 December 2020

INTRODUCTION

Aquaculture is an activity of great importance within the productive sector of any nation because it promotes favorable techniques to increase and preservation aquatic species (marine or freshwater),seen from an environmental or economic scope, it is dispensable to generate effective techniques to optimize the processes involved [1]. Currently, artisanal hatcheries promote the care of species for human consumption, however, rudimentary techniques are not often effective when trying to emulate or conserve a suitable habitat for certain species and as a consequence, it is not achieved a good production, such as the case of the production of Paiche [2].

In aquaculture in natural environments, there is no control of the number of species, therefore, the parameters that the water must possess are not entirely controllable. Faced with this need, there are ponds for the breeding of certain species, avoid their closure and preserve them from falling into danger of extinction. For this reason, this project proposes a pH and level control system in fish tanks, being the first the main cause of fish mortality in aquariums due to the increase in the acidity of the water inside an aquarium due to excess dirt [3].

THE IMPORTANCE OF WATER pH IN AQUACULTURE

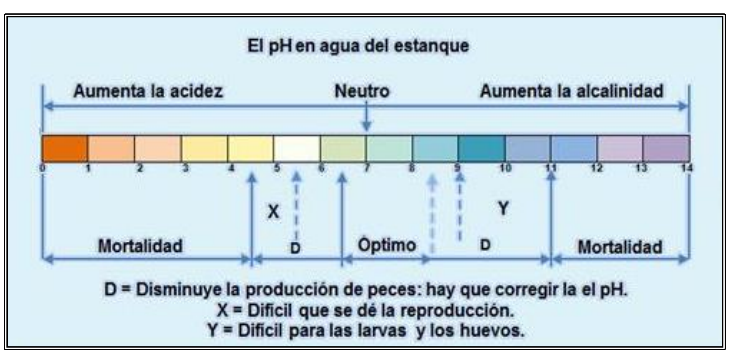

Figure 1: "The pH in pond water"
Fuente: PISCICULTURA GLOBAL [4]

Among the main factors that must be considered to maintain the salubrity of water in fish tanks for aquaculture are pH, temperature, dissolved oxygen, turbidity, and amount of metals. In aquaculture, favorable pH values are those within the range of 6.5 and 8.5. Although, there are singularities depending on each species, it is a generic value to establish as the optimum pH.

MEASUREMENT SENSORS

PH SENSOR

The sensor to be used is an E-201 probe whose connector is of typeBNC, for which there is a sensor module pH V1.1, whose characteristics are the following:

- Probe to measure pH Measurement range: 0.00 ~ 14.00 pH
- Alkali error: 0.2 pH
- Response time: = 1min

Figure 2: "pH sensor with control module"
Source: UNIT Electronics[5]

LEVEL SENSOR

The sensor to determine the water level during the pH control is the JSN-SR04T ultrasound sensor which works through sonars emitted in the direction of the water surface and it can detect liquid in a range of 25 to 450 cm, in addition, it is high precision and waterproof.

- Supply voltage: 5V DC
- Working current: 30mA
- Detection range: 25cm - 450cm
- Accuracy: + -0.3mm

Figure 3: "JSN-SR04T Ultrasonic Sensor"
Source: Naylamp Mechatronics - Peru [6]

PID CONTROL

The PID algorithm is the most common and used in control systems. Almost all closed loop control systems are controlled through the PID algorithm. This algorithm is implemented as a single controller or as a direct digital control package. Control and instrumentation engineers around the world use this PID algorithm in their processes. It is important to note that most industrial controllers used today contain PID control systems and these provide fine tuning of the PID control parameters, for which different tuning methods have been developed. It is important to indicate that in this industry modified PID control such as P control, PI control and PID control with two degrees of freedom are used. [8] These PID control algorithms are very useful for process control systems, as they provide satisfactory control. [9]

ANALOG PID CONTROLLER DESIGN

Knowing the tuning methods mentioned above, we will define basic concepts and operations of each modified PID algorithm most used in process control systems. The mentioned control algorithm consists of three fundamental parameters which are: Proportional gain (P), Integral (I), and Derivative (D). [10]

Proportional controller (P)

This proportionality parameter (P) measures the error that exists between the current value and the output value or Set Point and applies the correction so that this error is minimal.

$u(t) = KP.e(t)$, applying the Laplace transform it would be: $C_p(s) = K_p$

Proportional Integral Controller (PI): It is defined through the following equation:

$u(t) = K_p e(t) + \frac{K_p}{T_i}\int_0^t e(\tau)d\tau$, Where T is the integral time constant, applying the Laplace transform, the transfer function would be: $C_{PI}(s) = K_p(1 + \frac{1}{T_i s})$

Proportional derivative controller (PD):

This action makes the response to the control be faster, however, at the same time it makes it more sensitive improving the precision of the system. It is defined by the following equation:

$u(t) = K_p e(t) + K_p T_d \frac{de(t)}{dt}$, where Td is the derivative time constant, applying the Laplace transform, the transfer function would be: $C_{PD}(s) = K_p + sK_p T_d$

Proportional integral derivative (PID) controller:

This action combines the advantages of each of the individual actions mentioned above. [11]

The PID control equation is: $u(t) = K_p e(t) + \frac{K_p}{T_i}\int_0^t e(\tau)d\tau + K_p T_d \frac{de(t)}{dt}$, applying the Laplace transform, the transfer function would be: $C_{PD}(s) = K_p(1 + \frac{1}{T_i s} + sT_d)$

LEVEL PLANT MATHEMATICAL MODEL

For the mathematical modeling of the hydrodynamics of the fish tank is considered a tank, a centrifugal pump with a frequency variation, a controller, and level transmitter are considered, these are not part of the system, therefore, they do not intervene in the modeling of the plant.

The variables that are important for the modeling plant are the inlet flow, outlet flow, the restriction or resistance that is the shape of the outlet pipe, the height, and the area of the base of the tank.

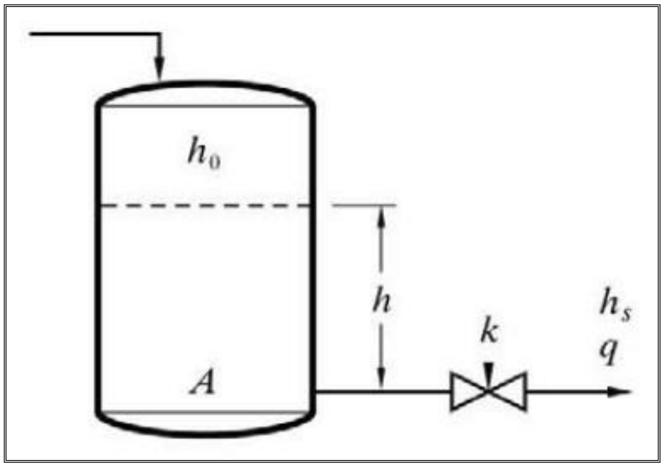

Figure 4: "Variables in a tank control system"
Source: Book Automatic control of industrial processes [7]

We must define that the outlet flow will depend on the restriction, that is, the type and shape of the pipe. The valve does not intervene as it is manual and controlled by the ATMEGA controller.

The height depends on the flow, that is, the higher the flow, the higher the height, and of the restriction.

The incoming flow must be sufficient so that there is a flow at the outlet. Thus:

$$q(t) = q_r(t) + q_a(t)$$ Equation N° 1

Where:

$q(t)$ = Inlet flow

$q_r(t)$ = Flow through the pipe

$q_a(t)$ = Flow accumulated at the base of the tank

The height is proportional to the flow, so

$$h(t) = g(t).q(t)$$ Equation N° 2

Where:

$h(t)$ =Height.

$g(t)$ = It is the relationship between the height and the flow

Applying Laplace transform to equations 1 and 2, with initial conditions equal to zero, we would have:

$$Q(s) = Q_r(s) + Q_a(s)$$ Equation N°3

$$H(s) = G(s).Q(s)$$ Equation N°4

Remaining the transfer function in relation to the flow and the height:

$$G(s) = \frac{H(s)}{Q(s)}$$ Equation N°5

Constant parameters to consider are:

R= It is the restriction or resistance in s/m^2

A = is the area of the tank base in m^2

For the modeling we are going to consider 2 cases, the first that there is no accumulation, it means that the flow that enters is equal to the flow that leaves, from which we will obtain the following relationship: $h(t) = q_r(t).R$, applying the Laplace transform and clearing the flow, it would be:

$$Q_r(s) = \frac{1}{R} H(s) \quad \text{Equation N° 6}$$

In the second case that it accumulates in the lower part of the tank, we must consider the following relationship:

$$h(t)A = \int q_a(t)dt \quad \text{Equation N° 7}$$

in which applying the Laplace transform and solving (considering initial conditions equal to zero) we obtain:

$$Q_a(s) = As \cdot H(s) \quad \text{Equation Nº 8}$$

As we considered in equation N°1, the inlet flow is equal to the outlet flow. And doing the Laplace transform, it results:

$$Q(s) = Q_r(s) + Q_a(s) \quad \text{Equation Nº 9}$$

Replacing equation 6 and 7 in equation 8, we obtain:

$$Q(s) = \frac{1}{R} H(s) + AsH(s) \quad \text{Equation Nº 10}$$

Solving and simplifying we have the transfer function of the tank:

$$G_p(s) = \frac{H(s)}{Q(s)} = \frac{R}{1+RAs} \quad \text{Equation Nº11}$$

METHODS

It is designed A control system over control, through which the activation of the PID control will be controlled by means of an ON/OFF control provided by the reading of the pH sensor. The following flow chart shows the sequence of processes carried out by the automated system:

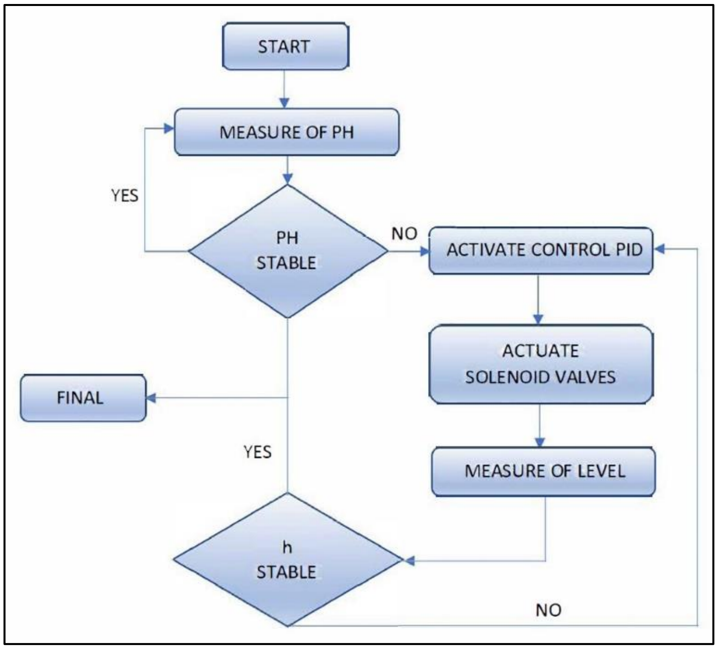

Figure 5: "flow system diagram"

LEVEL CONTROL MODELING SIMULATION

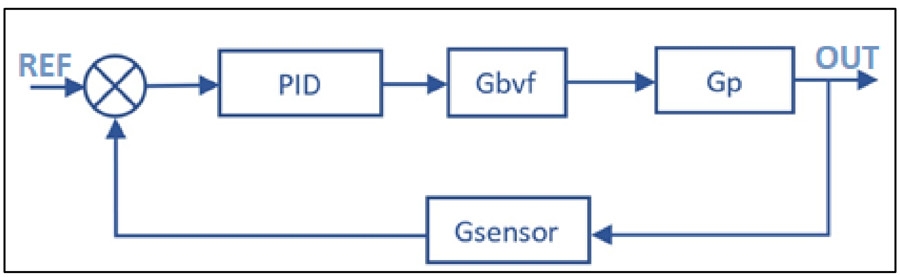

Figure 6: "Process block diagram"

The transfer function of the centrifugal pump with the variable of frequency drive (Gbvf), which delivers a maximum flow($Q_{\max}$) de $0.0083\ m^3 / s$ and network frequency(F_{red})de 60 Hz, it will be: of 60Hz.

$$G_{bvf} = \frac{Q_{\max}}{F_{red}}$$ Equation Nº12

The transfer function of the sensor block (Gsensor) is defined by the level transmitter that will measure from 0.05m to 1m, which gives us an effective measurement of 0.95m. With which considering a safety margin to prevent overflow, then the maximum height($H_{\max}$) It will be:

$$H_{\max} = 0.80\ m.$$ Equation N° 13

As the sensor has a very small delay with respect to the plant, then the height of the tank will send it as it is, to the comparator, therefore, it will consider its transfer function with the following equation:

$$G_{sensor} = 1$$ Equation Nº14

The base area (A): $A = 1.2x0.8 = 0.96\ m^2$

The transfer function of the PID block will be:

$$PID = K_P + \frac{K_I}{s} + sK_D \qquad \text{Equation N°15}$$

Considering a smooth flow behavior, we can obtain the relation of the restriction R:

$$R = \frac{H_{prom}}{Q_{prom}} \qquad \text{Equation N°16}$$

Where we consider the medium height (H_{prom}) and the medium flow (Q_{prom}) to an 80% of the maximum measured.

$$H_{prom} = (H\max)(0.8) \qquad \text{Equation N°17}$$

$$Q_{prom} = (Q\max)(0.8) \qquad \text{Equation N°18}$$

DETERMINATION OF CONSTANTS OF PROPORTIONALITY

For the control system we choose the PI control, which best adapted to the proposed transfer function and we generate the variables, K_p, K_I y K_D through the *pidtools* (sys) command. The variables generated by the command are close to a stable response, however, it needs a manual modification of constants to choose the strongest and fast response control so that the system can work effectively.

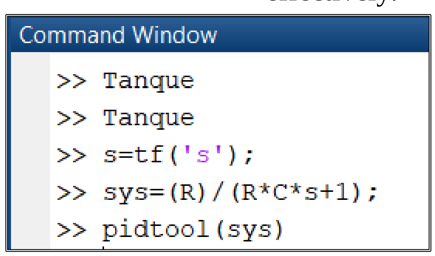

Figure 7: "Generation of control variables"

$K_P = 33.85, K_I = 5.34$ y $K_D = 0.09$, these values are stored in the PID functional block.

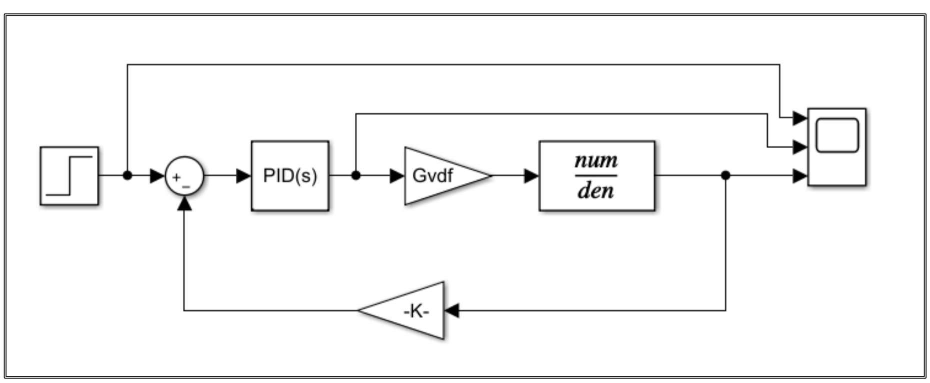

Figure 8: "Diagram of the function at a step input "

We observe that the control stabilizes in a time of 30 seconds.

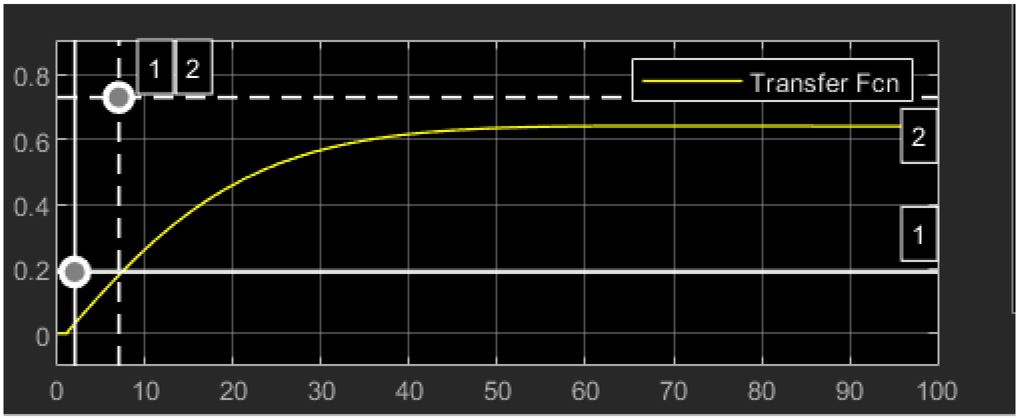

Figure 9: "Response in Scope of the applied PID control"

SYSTEM CIRCUIT AND EXPLANATION OF ITS OPERATION

The circuit was implemented with an Arduino Mini microcontroller, the pH and level sensors as sensing components and at the same time a 24V electric pump as an actuator, which was adapted by means of a mosfet to be associated with an input on the Arduino board to control its PWM. The microcontroller will measure the pH constantly and when it detects an abnormality in the standard value, it will start to drain the liquid to activate the PID and in this way the process will be repeated until the stabilization of both constants is achieved.

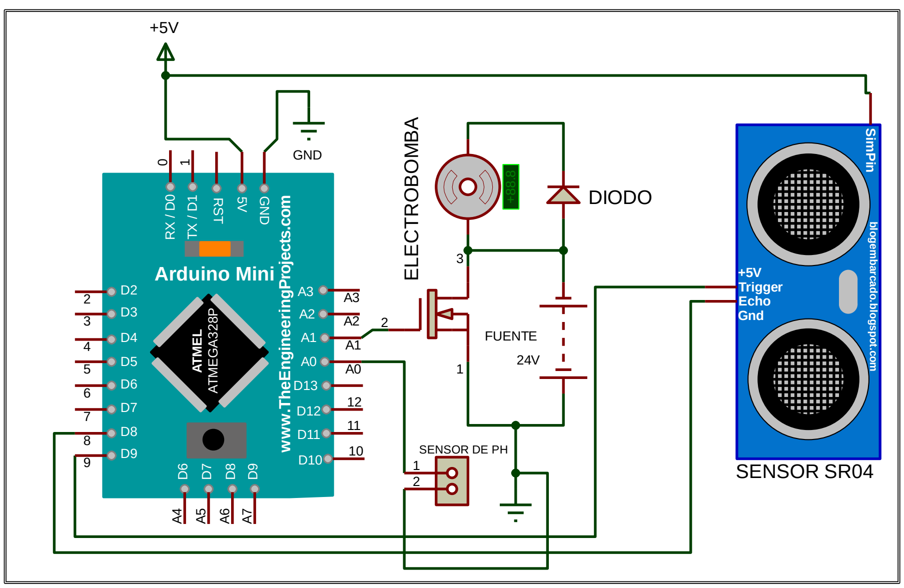

Figure 10: "Simulated circuit in Arduino"

RESULTS

- As we can see in figure 10, the level of the tank does not exceed its maximum height, which indicates that after the liquid has been discharged according to the programming, there will be a control until reaching the *Set Point* given by 64cm according to what was programmed.

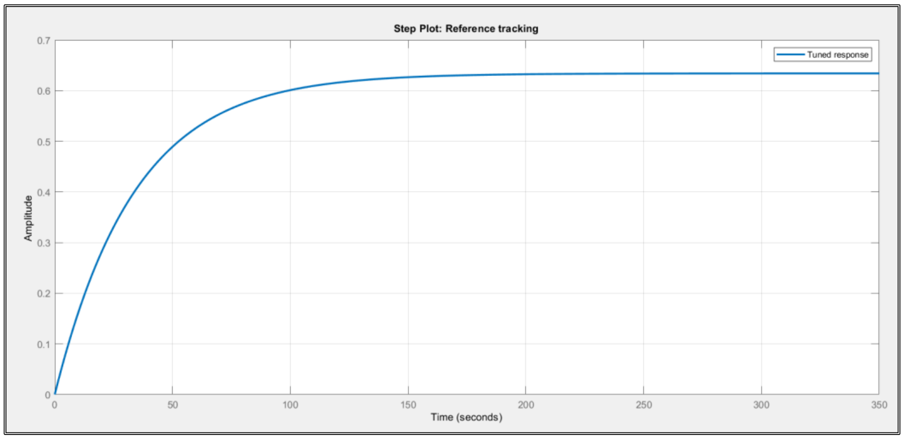

Figure 11: "Reference level monitoring"

- Protection micromesh was implemented in the outlet valve to avoid loss of gravel or fry when stabilizing the pH levels and water level.
- The turbidity of the water, an important parameter to keep the water in good quality conditions for breeding, was reduced. In this way, a third unplanned variable regulation was achieved.

CONCLUSIONS

- To obtain a stable control of two variables using conditionals within the programming in the microcontroller, it was required to destabilize the system in order to let the PID control act and involve it in a loop until obtaining the desired values, this guarantees that there are no conflicts in the microcontroller programming.
- The simulation work after implementing the PID controller is better than that implemented with an ON / OFF control, because, as shown in figure 8, there are no unbalance peaks in the response graph, indicating that there are not many disturbances.

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