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# Efficient and low-cost temperature automated system for aquariums in fry hatcheries using control algorithms

**Macedo, Julio***
**Díaz, Enrique****
**Gutiérrez, Ricardo*****
**Marín, William******

## Abstract

The purpose of this research is aimed to bring an alternative solution for the raising of fry in aquatic ponds, through the control and monitoring of water temperature, in order to optimize their development and growth, regardless of the habitat where they are located, improving the production of fish for mass consumption even in places where the climate is not suitable for their raising. The above-mentioned control and monitoring was carried out through the cost-effective Atmega328P microcontroller that make easier its configuration and implementation. This type of research is applied because it gives solution to the problem in optimize the fry raising in aquariums and was divided into the following stages for temperature control: first, the sensor measures the temperature and compares it with a mobile application baseline; second, the water temperature is stabilized by the electronic thermostat; finally, the water temperature is conditioned to get a healthy habitat for the fry. All of this is executed remotely through an application created to be used from a cell phone. Concluding, the right parameters are found to stabilize the water temperature effectively.

**Keywords:** Aquariums; fingerlings; automation; control algorithms; water temperature.

* Doctor en Ciencias de la Educación. Docente Principal en la Universidad Nacional José Faustino Sánchez Carrión, Huacho, Perú. Investigador RENACYT reconocido por CONCYTEC. Scopus Author ID: 57212082627 E-mail: jmacedo@unjfsc.edu.pe ORCID: https://orcid.org/0000-0002-2827-317X

** Doctor en Ciencias de la Educación. Docente del Departamento de Ciencias en la Universidad Privada del Norte, Lima, Perú. Scopus Author ID: 57328227300 E-mail: enrique.diaz@upn.edu.pe ORCID: https://orcid.org/0000-0003-1886-0693

*** Maestro en Investigación y Docencia Universitaria. Docente en la Universidad Privada del Norte, Lima, Perú. Scopus Author ID: 56236798300 E-mail: ricardo.gutierrez@upn.edu.pe ORCID: https://orcid.org/0000-0002-6800-6981

**** Maestro en Administración Estratégica. Docente Asociado en la Universidad Nacional José Faustino Sánchez Carrión, Huacho, Perú. Investigador RENACYT reconocido por CONCYTEC. Scopus Author ID: 57222415761 E-mail: wmarin@unjfsc.edu.pe ORCID: https://orcid.org/0000-0002-0861-9663 (Autor de correspondencia).

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# Sistema automatizado de temperatura eficiente y de bajo costo para acuarios en criaderos de alevines usando algoritmos de control

## Resumen

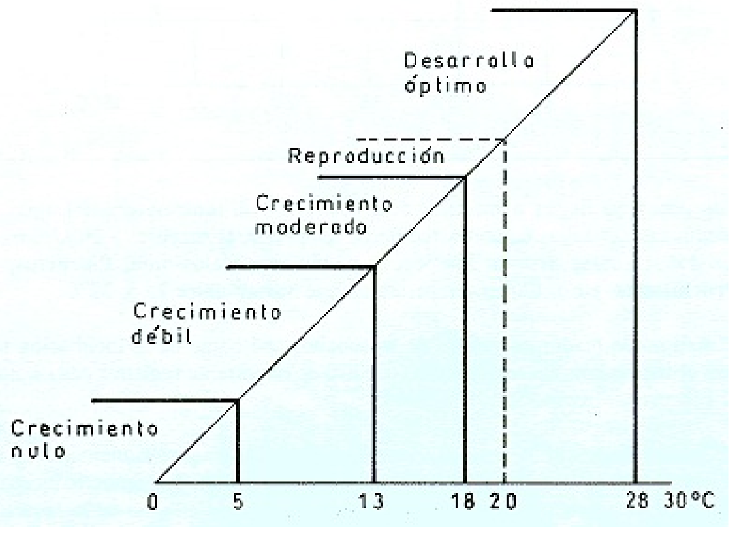
El propósito de esta investigación está dirigido a brindar una alternativa de solución para la crianza de alevines en estanques acuáticos, a través del control y monitoreo de la temperatura del agua, con el fin de optimizar su desarrollo y crecimiento, independientemente del hábitat donde se encuentren, mejorando la producción de peces para el consumo masivo incluso en lugares donde el clima no es propicio para su crianza. El control y monitoreo antes mencionado se realizó a través del microcontrolador Atmega328P de bajo costo que facilita su configuración e implementación. Este tipo de investigación es aplicada porque da solución al problema de optimizar la crianza de alevines en acuarios y se dividió en las siguientes etapas para el control de temperatura: primero, el sensor mide la temperatura y la compara con una línea base de aplicación móvil; segundo, la temperatura del agua es estabilizada por el termostato electrónico; finalmente, se acondiciona la temperatura del agua para conseguir un hábitat saludable para los alevines. Todo esto se ejecuta de forma remota a través de una aplicación creada para ser utilizada desde un teléfono celular. En conclusión, se encuentran los parámetros correctos para estabilizar la temperatura del agua de manera efectiva.

**Palabras clave:** Acuarios; alevines; automatización; algoritmos de control; temperatura de agua.

## Introduction

In aquaculture, an alternative production of freshwater fish for popular food, the control of effective techniques for healthy raising and production of aquatic species is determined by water quality and its parameters. However, when we talk about production and life expectancy of nascent species, the water temperature, where eggs and fry are bred the first days of life is essential for their survival, such is the case of the raising of *arcoiris* trout fry (Organización de las Naciones Unidas para la Alimentación y la Agricultura [FAO], 2014).

The fry pond is fed with tap water whose temperature is between 15ºC to 18ºC, sometimes this can change depending on the climate, the hydraulic connection, among others. There are cases such as in red tilapia fry hatcheries, where the fry does not survive due to very low temperatures, causing cessation of feeding, diseases or even the death of the species (Secretaría Pro Tempore, 1992). This is why water temperature is so important for the development and growth of fish, as shown in Figure I.




**Source:** Secretaría Pro Tempore (1992).

**Figure I: Influence of temperature on the growth of fishes**

The purpose of this research is aimed to bring an alternative solution for the raising of fry in aquatic ponds, through the control and monitoring of water temperature, in order to optimize their development and growth, regardless of the habitat, and improve the production of fish for mass consumption even in places where the climate is not suitable for raising, contributing, in this way, in the economic and social sector.

## 1. Theoretical foundation

### 1.1. Aquaculture

Aquaculture are the executions, techniques and information required for the fish and plants raising. Aquaculture contributes greatly to the economy of a country. Fish obtainment expands every day since its protein intake is almost 15% so it is required by the population (Saha, Hasan & Kabir, 2018).

### 1.2. Depth of ponds for fry

The ideal water depth of the ponds for fry raising should range from 0.7 to 1 m., avoiding in this way that aquatic plants and different algae development can cause problems to the raising. Likewise, a maximum height of 2 meters is recommended. These measures benefit the raising system (Lezama & Balladares, 2017).

The oxygen amount in the water is an important factor for the survival of the fry, because this concentration is related to temperature, that is, when the higher the temperature is, less dissolved oxygen in the water. For this the reason is very important can control the temperature in which the fish lives, to have a better raising (Lezama & Balladares, 2017).

## 1.3. Mortality and survival of fry

The fundamental factor for the production and raising of fry is environment, so, it is important to take into account information about mortality and survival of these. The fry mortality is determined by the number of fish that died in raising period; and fry survival, by the number of survivors from incubation period until their growth during the counting, taking into account the following formulas (Rabinovich, 1978):

$$A = \frac{N_O - N_F}{N_O} * 100 \qquad S = 100 * A$$

Where: S is survival, and A is mortality.

Water temperatures, oxygenation, pH, alkalinity and hardness are the possible biological factors that cause a high mortality rate. Therefore, the water quality where the fry fishes are raised must be optimal to ensure their growth and survival (Muñoz & Bernal, 2008).

## 2. Sensors and actuators

### 2.1. Aquatic thermostat

In CGnauta Blog (2016), the thermostat is an actuator that will be used inside the pond, whose function is heat the water in the pond. This device is coated with a capsid to resist in aquatic environments, which is made of borosilicate glass and plastic. The device is designed to withstand both fresh and salt water. The measurement of the fry tank must be considered in the election of thermostat, which is determined by:

$$Volumen = (1.2)(0.8)(0.7)$$
$$Volumen = 0.192m^3$$

In order to choice a thermostat must be considered: 1 Watt per liter of water (Rubio & Chotón, 2015). Therefore, a 200 W thermostat is used, as shown in Figure II.

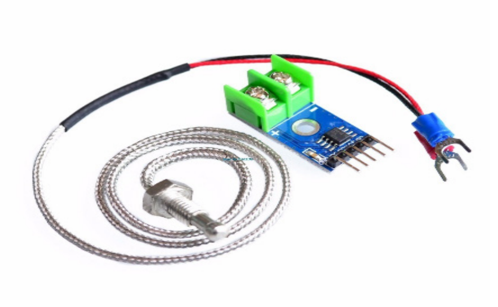

**Source:** Cgnauta Blog (2016).

***Figure II:*** **Aquatic thermostat**

### 2.2. Thermocouple type K + Module MAX6675

This device is ideal to measure up to 1200º C, and is very useful in the industry, due to its high sensitivity to temperature variations; however, its performance decreases when it goes through very high temperatures (Fernández-Betancourt, 2013).

Type K thermocouple (shown in Figure III) will be used for the correct measurement of the temperature in the system, because it is a high precision sensor, with the following characteristics, according to Industrias Tezla (2017): a) Read-only SPI compatible interface; b) 12-bit resolution, 0.25 degrees Celsius; c) Measurement up to 1024 degrees Celsius; d) Power from 3.3 to 5 volts; e) Maximum SPI clock frequency Fscl 4.3 Mhz; f) Conversion time 0.17 s maximum 0.22 seconds; g) Maximum consumption of 1.5 mA.



**Source:** Industrias Tezla (2017).

***Figure III:*** **Termocouple type K + MAX6675**

### 2.3. Calibration of the sensor

In Table 1, are shown the temperature reading values, measured and obtained for the correct calibration of the sensor.

**Table 1**
**Temperature reading values**

| DATA | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SENSOR | 29.3 | 29 | 29 | 29 | 29 | 29.3 | 29 | 28.8 | 29.3 | 29.3 | 29.3 | 29 | 29 | 29 | 29.3 | 29.3 | 29.3 | 29.3 | 28.8 | 29 |
| THERMOMETER | 29.5 | 29.3 | 28.8 | 29.5 | 29.5 | 28.8 | 29.8 | 29.8 | 29.5 | 29.5 | 29.8 | 29.5 | 29.3 | 29.5 | 29.5 | 29.5 | 29.8 | 28.8 | 28.8 | 29.5 |

**Source:** Own elaboration, 2022.

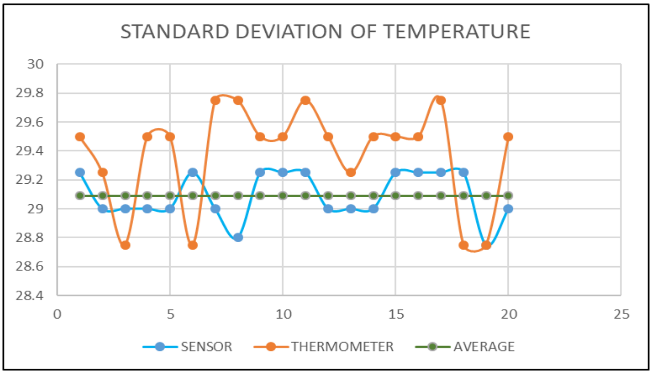
Standard desviation $(\sigma)$:

$$\sigma = \sqrt{\frac{\sum_{1}^{n}(x_i - \bar{x})^2}{n}} = 0.163$$

Relative error (%):

$$e = \frac{V_{real} - V_{\exp}}{V_{real}} x100\% = 0.95\%$$

In Figure IV, are shown the values measured by the temperature sensor and the thermometer, in addition to the average temperature.




**Source:** Own elaboration, 2022.

***Figure IV:*** **Standard deviation of temperature**

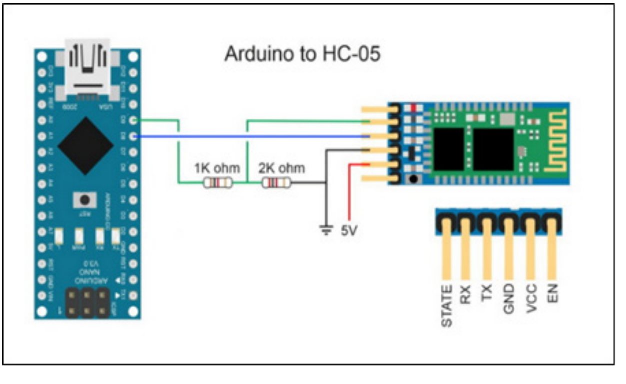
## 2.4. Bluetooth module (HC-05)

According to Torres (2020), the HC-05 module is a device manufactured to establish a bluetooth communication compatible with the Atmega328P microcontroller through a mobile device and also to control and monitor the water temperature, for the purposes may be convenient for the user.

According to Currey (2017), the module has the following features: a) Bluetooth protocol: v1.1 / 2.0; b) Frequency: 2.4 GHz ISM band; c) Transmission power: Less than 4dBm, Class 2; d) Sensitivity: Less than -84dBm at 0.1% VER; e) Power supply: + 3.3VDC 50mA (supports 3.3 to 6V); f) Working temperature: -5 ° C to 45 ° C.

## 2.5. System circuit and explanation of its operation

The circuit was implemented with an Arduino Nano microcontroller, a Type-K thermocouple implemented with a MAX6775 control module, an aquatic thermostat and a Bluetooth connection module (HC-05), as shown in Figure V.

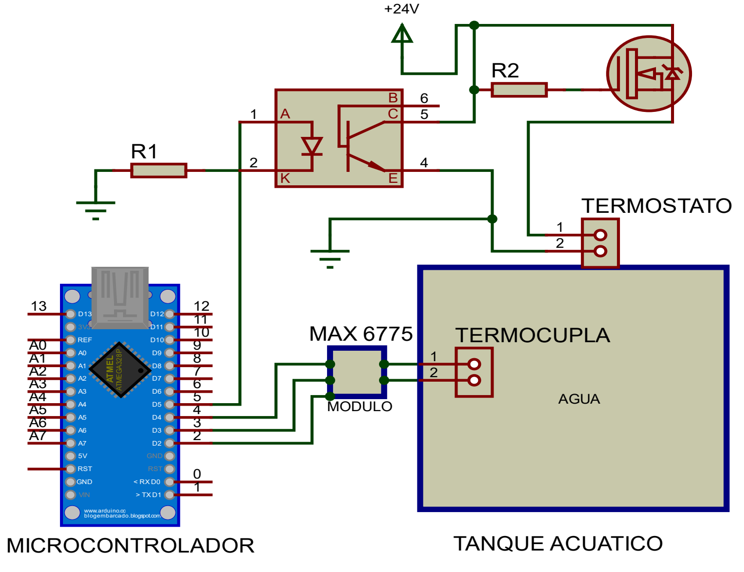



**Fuente:** Industrias Tezla (2017).

***Figure V:*** **Connection of the bluetooth module and the MAX6775 module**

The thermocouple operates throughout the process to calculate the current temperature value of the water as the proportional and integral control; it will be activated through the thermostat to keep the water in the condition determined by the user. Only, when the "set point" has raised the reading value of the thermocouple, the control will stop.

For the control of the load coming from the actuator, a MOC optocoupler is implemented with a MOSFET field effect transistor, which exceeds the 5V provided by the ARDUINO NANO microcontroller. Finally, the bluetooth module HC-05 will remain active to establish connection through mobile application and thus vary the "set point" according to the species to which the pond is intended. In Figure VI below, is shown the circuit simulation using the Arduino Nano microcontroller.

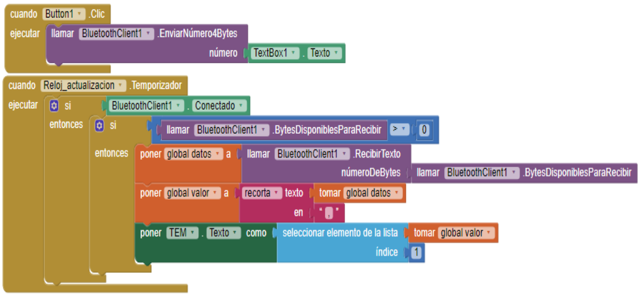



**Fuente:** Own elaboration, 2022.

***Figura VI:* Circuit simulation with Arduino Nano**

## 2.6. App Inventor application

For Android-type mobile operating systems was used the App Inventor application development environment. App Inventor, is an open block coding tool, designed in order to the user can make easy use of the tool badge and a follow-up of their projects (Programo Ergo Sum, 2019). In Figure VII, is shown the block programming of the Bluetooth module configuration for remote manipulation from the cell phone, developed in App Inventor.




**Source: Own production, 2022.**

***Figure VII:* Block coding in App Inventor**

Since the average ambient temperature is 25°C, a step change until the temperature stabilizes at approximately 30°C is used. Therefore, the value $\Delta u = 5$. Data obtained is exported to an Excel table, as is shown in Figure VIII, where the value of the profit $k = \frac{Tf - Ti}{\Delta u}$ and the "tao" time are found.

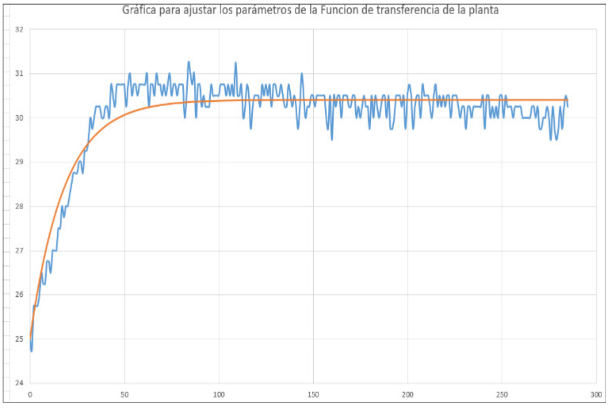
| | | | | | |
|---|---|---|---|---|---|
| 4 | deltaU | 5 | | | |
| 5 | | | | | |
| 6 | tiempo | tempC | | | |
| 7 | 0 | 25 | | 25 | 0 |
| 8 | 1 | 24.75 | | 25.29011 | 0.291713949 |
| 9 | 2 | 25.75 | | 25.56464 | 0.034356846 |
| 10 | 3 | 25.75 | | 25.82445 | 0.005542927 |
| 11 | 4 | 25.75 | | 26.07032 | 0.102602655 |
| 12 | 5 | 26 | | 26.30299 | 0.091802367 |
| 13 | 6 | 26.5 | | 26.52318 | 0.000537148 |
| 14 | 7 | 26.25 | | 26.73155 | 0.231889115 |
| 15 | 8 | 26.25 | | 26.92874 | 0.460687527 |
| 16 | 9 | 26.75 | | 27.11535 | 0.133480209 |
| 17 | 10 | 26.75 | | 27.29195 | 0.293705219 |
| 18 | 11 | 26.5 | | 27.45907 | 0.919807572 |
| 19 | 12 | 27 | | 27.61722 | 0.38095877 |
| 20 | 13 | 27 | | 27.76688 | 0.588112189 |
| 21 | 14 | 27 | | 27.90852 | 0.825408287 |
| 22 | 15 | 27.5 | | 28.04255 | 0.294365743 |
| 23 | 16 | 27.5 | | 28.1694 | 0.448093065 |
| 24 | 17 | 28 | | 28.28943 | 0.083771981 |
| 25 | 18 | 27.75 | | 28.40303 | 0.426447049 |
| 26 | 19 | 28 | | 28.51053 | 0.260639733 |
| 27 | 20 | 28 | | 28.61226 | 0.374862559 |
| 28 | 21 | 28.25 | | 28.70853 | 0.210252197 |
| 29 | 22 | 28.5 | | 28.79964 | 0.08978362 |
| 30 | 23 | 28.75 | | 28.88586 | 0.018457094 |
| 31 | 24 | 28.75 | | 28.96745 | 0.047283722 |
| 32 | 25 | 28.75 | | 29.04466 | 0.086825311 |
| 33 | 26 | 29 | | 29.11773 | 0.013860648 |

Sheet1

**Source:** Own production, 2022.

***Figure VIII:* Data obtained from the open loop temperature sensor in Excel**

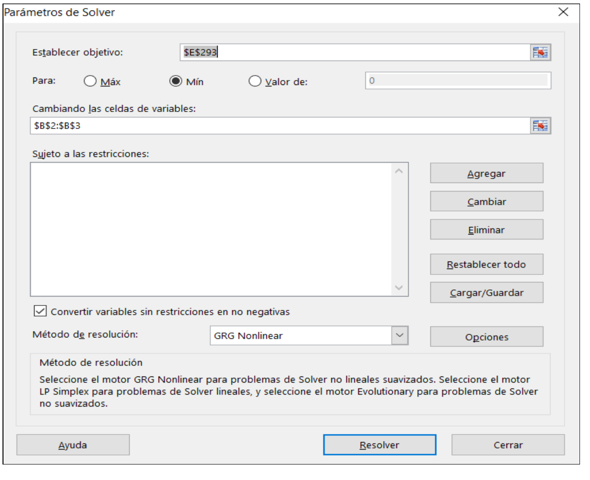
From the formula: $y(t) = k(\Delta u)\left[1 - e^{(-t/\tau)}\right] + 25$ the values shown in column “B2” are obtained in order to compare the experimental data with the theoretical ones. For the following answers, see Figure IX.




**Source:** Own production, 2022.

***Figure IX:*** **Open loop system response**

The blue signal is the experimental response and the orange is the theoretical response. The Solver add-on, as shown in Figure X, is used to minimize the measurement error.




**Source:** Own production, 2022.

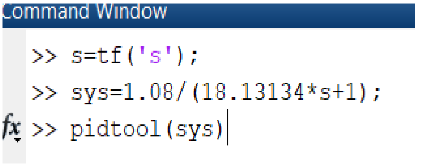
***Figure X:*** **Solver parameters**

Finally, with the values obtained from K and Tao, the following transfer function is obtained:

$$G_p(s) = \frac{1.08}{18.13134s+1}$$

## 2.7. Design of proportional, integral and derivative (PID) analog controller

In order to determine the values of the PID parameters of the plant, starts by invoking the "pidtool" tool, in which the transfer function obtained previously will be used to get the values of the parameters of Kp corresponding to the proportional gain; Ki which is the integral gain; and, Kd which is the derivative gain. Generating system response and Kp, Ki and Kd values, as seen in Figure XI.

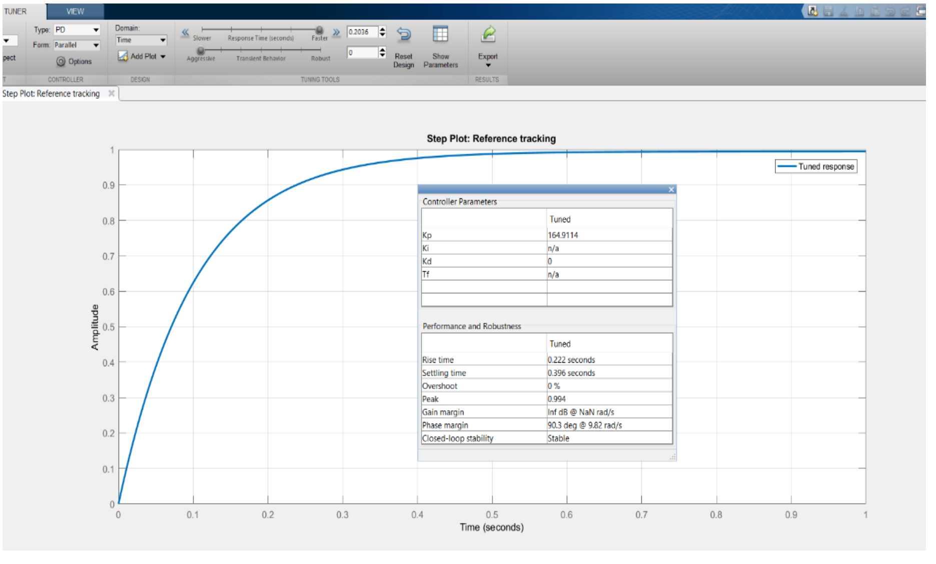



**Source:** Own production, 2022.

***Figure XI:*** **PIDTools Command**

## 3. Results and discussion

The system water temperature was stabilized through the control of Pulse Width Modulation (PWM) of the thermostat, therefore, a more favorable environment was generated for the fry raising, as shown in Figure XII.




**Source:** Own production, 2022.

***Figure XII:*** **Control system response**

This result allows to automate the pond with a microcontroller Atmega, which is a cost-effective device, since through the parameters found it is possible to control the temperature effectively and stably. This project is of great importance in the social and economic environment due to technological progress, which after the Covid-19 pandemic allows the remote monitoring for fry raising.

## Conclusions

It was possible to design a device that adapts the water temperature where the fry resides, a technological proposal that allows ensuring the effective production of fish for mass consumption even in places where the climate is not suitable for fry raising, bringing great benefit to the population in decentralized places.

A closed loop system was designed for temperature control, using the ATMEGA328P microcontroller which allows the actuation of the thermostat. Also, an application was developed to modify the variable temperature to a desired value, without needing to be physically in place and make a monitoring of the pond in real time.

Working with a single heat actuator, generates small delays in time when controlling the temperature variable, for which a cold actuator is recommended to compensate and maintain a more precise control. The device is of low cost of implementation which benefits low-income residents living in decentralized areas, the possibility of dedicating themselves also to the raising of fry fishes despite the climate they inhabit.

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