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INDUSTRIAL APPLICATION CONTROL WITH FUZZY SYSTEMS

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Abstract. *As it knows most of the quotidian problems are not simply to evaluate and considerate formal modeling based in traditional techniques is not the answer. What all industries look is always to be better about production and control process that is the reason why the word control is common. The technical development to process control is increasing as faster as industry necessities. The process control makes the evaluation and executions more efficient in the industry. This article was made with the purpose to compare two types of control, one with Fuzzy logic and the second one with PID control. The manuscripts show the advantages and disadvantages of each one, about controlling a temperature plant, in accordance with the functional parameters.*
Keywords: Fuzzy control, Industrial automation, PID control

1. **Introduction.** With the growth of the technology and the demand for improvement in the industry, require accurate control systems, to optimize the intern process in selves and take parameters more exactly giving some values to parameters what are not measurable.

A control system is a components set that affects the operation and performance of the entire system. All the control systems need to be capable of ensuring stability, efficiency and having the facility to implement in the system [1,2].

As it knows, some control systems are the PID and Fuzzy control, both of them with the same function, dynamic control systems, dependent of the precision and every time that precision has to increase the system control is more difficult because they are too sensitive to the noise.

The Fuzzy logic is completely useful because as it knows the behavior almost of everything is not always the top or the bottom value, and for evaluating the values, which are between the extremes. This logic can treat with inaccurate information based in some rules about Fuzzy sets and make some decisions to decide to which part of extremes are going to be [1].

The Fuzzy control goal was to create an easier method to manipulate the imprecision the best way possible and associate with the human vague thought and their linguistic expressions [3].

The PID control is the most conventional tool for control process. Nowadays, the PID control is finding it in all industries, and the design comes in many different forms. The PID control is important for the distributed control system. The structure of a PID controller is as simple as its weak point, that is because its range of control is limited [4].

The goal of this project is to compare what the Fuzzy control can do against a PID, which is a classical control. The comparisons are made with: error, stability, overshoot and response time.

2. **PID Control.** Since 1940, the PID control has been one of the most useful methods to control a process. Of course, the PID controller comes in different structures, with a different type of work method and various application fields [5].

The PID controllers are required in large quantities because it is one of the most used in industry. PID controller allows to give options those are possibilities to change the dynamics of any system and be useful for the designer [5]. Figure 1 shows schematics about classical control.

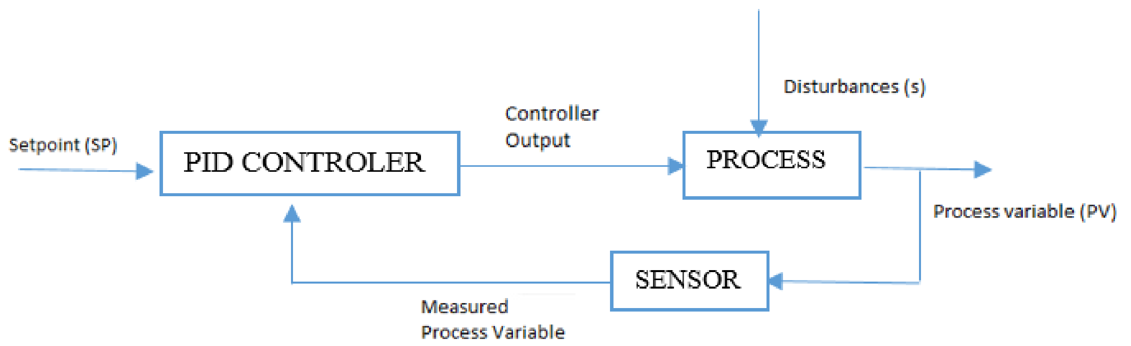

FIGURE 1. Feedback control system [5]

2.1. **Proportional control.** The proportional control output is the gain result of the proportional and the error, increasing the system velocity and decreasing the error inside the process.

The output is showed by Equation (1).

$$A_{out} = K_p \varepsilon \tag{1}$$

where: A_{out} = *Control Output*, K_p = *Proportional gain*, ε = *Process error signal*.

The effect of controlling the proportional gain is to reduce the rise time and the steady state error as well; when this happens, the tendency to oscillate will increase also.

2.2. **Integral control.** Equal as the proportional gain, the integral control is the amplification of the process error signal but in the time. The integral gain corrects the error induced for proportional error and it has a slower answer but the error is almost zero [6].

The integral control disadvantage is the overshoot time for oscillations due to increase.

The integral gain is defined mathematically by Equation (2).

$$A_{out} = \frac{1}{T_i} \int \varepsilon dt \tag{2}$$

A_{out} = *Control Output*, T_i = *Integral time*, $\int$ = *Process control*, ε = *Process error signal*, dt = *Time variation*.

2.3. **Derivative control.** The derivative gain is involved in reducing the overshoot time, decreasing during sudden disturbances. The derivative control predicts the possible error in the control system [6].

The derivative gain is defined mathematically in Equation (3).

$$A_{out} = T_d \frac{\Delta\varepsilon}{\Delta t} \tag{3}$$

A_{out} = *Control Output*, T_d = *Derivative time*, $\frac{\Delta\varepsilon}{\Delta t}$ = *Error variation over time variation.*

Practically the derivative gain can show the rate of change in the control system, reducing the setting time and the overshoot.

2.4. **PID control.** A PID controller is a mechanism to control the error between an average and ideal value, so then correct the process.

The PID controller is defined mathematically by Equation (4).

$$u(t) = K_p \left[\varepsilon(t) + \frac{1}{T_i} \cdot \int_{t_0}^{t} \varepsilon(t)dt + T_d \cdot \frac{d\varepsilon(t)}{dt} \right] \tag{4}$$

PID controller is used to deal with dynamics necessary having a fast input reaction (K_p), get down the steady state error until trying to make it zero (K_i) and consider the rate of change increasing the stability and the setting time as well.

Table 1 shows the effects of coefficients [8].

TABLE 1. Effects of coefficients [4]

Parameter	Response's speed	Stability	Accuracy
K_p	Increase	Deteriorate	Improve
T_i	Decrease	Deteriorate	Improve
T_d	Increase	Improve	No impact

To make the PID controller more accurate there are some methods to adjust the gain values.

2.5. **Tuning methods of control systems.** The tuning methods are used to adjust the values and found them for the desired control response; however, the behaviours of many systems are never equal and the control could be different from one to another [7].

Some of the tuning methods are:

- Manual tuning method;
- Ziegler and Nichols;
- PID tuning software methods.

The most used methods presented for Ziegler and Nichols are the *closed loop method* known as limit accurate, which allows calculating tuning parameters, following a procedure which comprise to put the integral and derivative value to their minimum value and the obtained gain it is denominated as "the last", (Ku), because the last sensibility is reached. The process will continue until it has a continuous oscillation [9].

Figure 2 shows a continuous oscillation when the process reaches the limit sensibility.

Table 2 defined the PID parameters for the Ziegler-Nichols method.

The other tuning method is the process reaction curve and used for open loop systems.

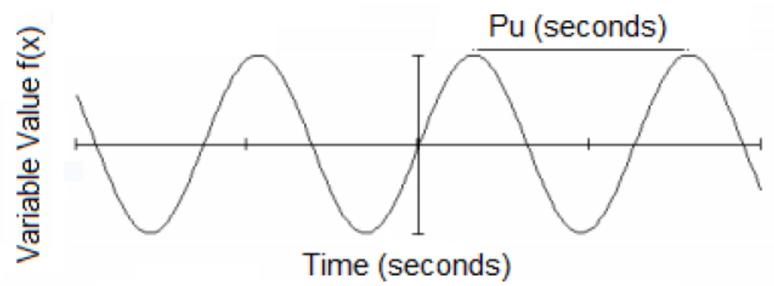

FIGURE 2. Continuous oscillation [9,10]

TABLE 2. Control parameters for the "Limit Gain" by Ziegler-Nichols [10,12]

Control Parameters	K_p	T_i	T_d
P	0.5*Ku		
PI	0.45*Ku	Pu/1.2	
PID	0.6*Ku	Pu/2	Pu/8

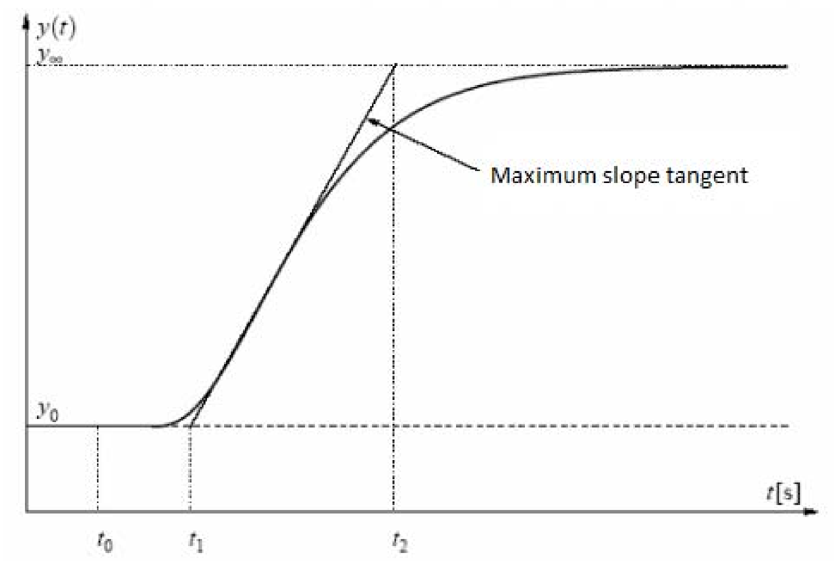

FIGURE 3. Process reaction curve [10,11]

Generating a disturbance in the process reaction curve, the response produces a quick-step little function change, is how this method works and it is shown in Figure 3 [10,11].

This method includes several parameters that can be measured as the dead time ($\tau_{dead} = t_1 - t_0$), the response time ($t_2 - t_1$) and the ultimate value when the system has reached the steady state (y_∞).

With the slope (R), the delay time (L) and Δp% what is the position variation, with this value it can calculate the control parameters as it shows in Table 3 [4,11].

TABLE 3. Control parameters for the reaction curve method

Control Parameters	K_p	T_i	T_d
P	100RL/Δp		
PI	110RL/Δp	L/0.3	
PID	83RL/Δp	L/0.5	0.5L

The Ziegler-Nichols method was deduced empirically; both of them are based in a process response when is provoked a perturbation. To optimize the system it is necessary to take the best and the worst conditions to have a wanted adjustment [11].

3. **Fuzzy Control.** The Fuzzy control is based in real numbers control and not only with Boolean parameters, it is a control.

The Fuzzy logic studies the control parameters in an approximate way; this kind of control is close to human language [11,13].

The Fuzzy logic arose to be one of the powerful tools of control process where there are complex industrial processes, because when there is a process there is a cost where the precision and certainty are involved [11,12].

If the logic is the science of the formal principles and reasoning rules, then, it can be said that the Fuzzy logic is referred of the formal principles and reasoning rules in an approximated way [11,12].

In Figure 4, it can see the Fuzzy sets of a Fuzzy control.

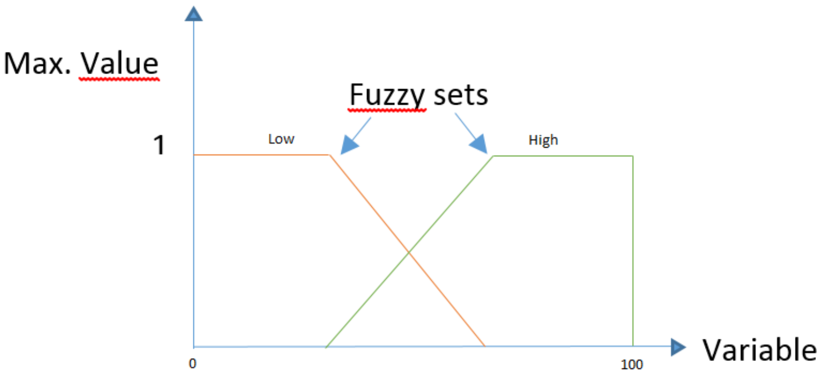

FIGURE 4. Example of linguistic variables [13]

A Fuzzy set tries to explain the system behaviour, defines the limits and helps us to make decisions, which can resolve problems. Along this chapter, it will be explained the Fuzzy sets operations.

3.1. **Union.** It is defined as the maximum of the two membership functions and called maximum criterion.

This theory and the OR operation are equivalent.

The equation proposed is defined by Equation (5) [3,13].

$$\forall_x \in X, \quad \mu_{A\cup B}(x) = \max(\mu_A(x), \mu_B(x)) \tag{5}$$

3.2. **Intersection.** It is applied to two Fuzzy sets, defined as the minimum of the two of them, and called the minimum criterion.

The equation proposed is defined by Equation (6) [3,13].

$$\forall_x \in X, \quad \mu_{A\cap B}(x) = \min(\mu_A(x), \mu_B(x)) \tag{6}$$

3.3. **Complement.** It is called the negation criterion, defined as the negation of the specified membership function.

The equation proposed is defined by Equation (7) [3,13].

$$\forall_x \in X, \quad \mu_{\bar{A}}(x) = 1 - (\mu_A(x)) \tag{7}$$

4. **Tests Results.** It was applied a test to a temperature plant using a temperature sensor. The sensor is mounting in a box with a relay and resistance to warm the environment.

Figure 5 shows the equipment used for the test.

The system flowchart in a general way can be shown in Figure 6.

One of the control methods (Fuzzy) and how it works are shown in Figure 7.

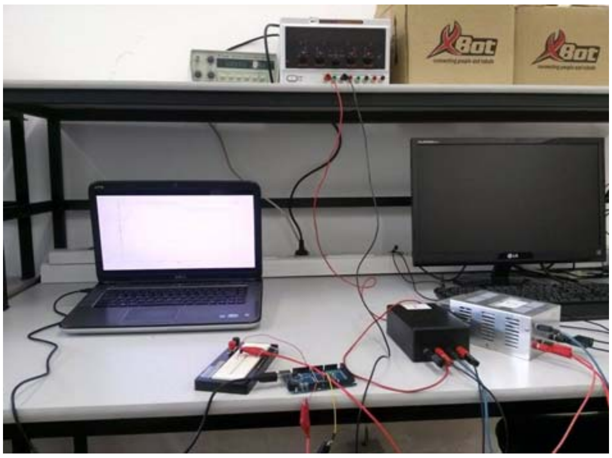

FIGURE 5. The experimental setup

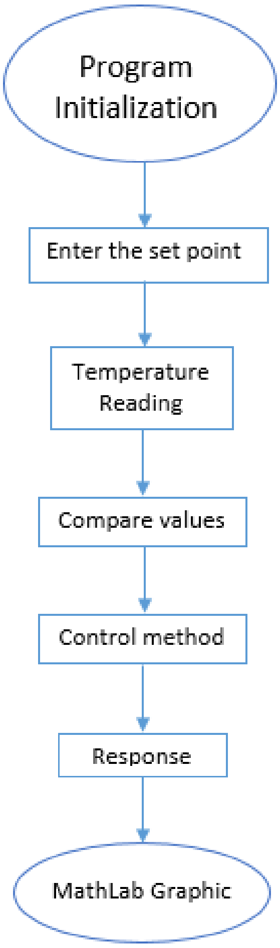

FIGURE 6. Temperature plant flow chart

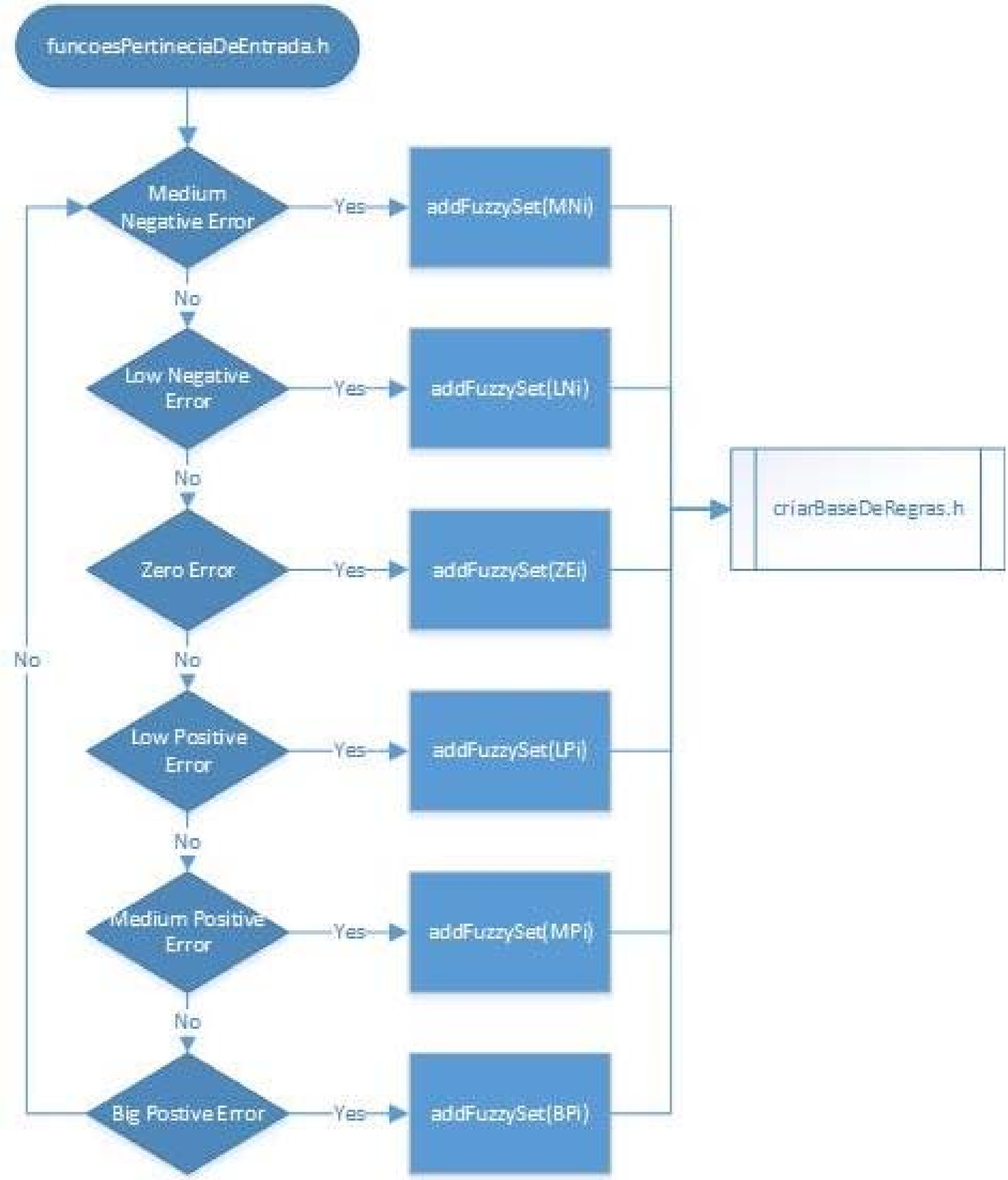

FIGURE 7. Input relevance function

The function input relevance the process continues, entering the "creating rule base". In this part, Figure 8 can show the Fuzzy process for the input data.

This goes through of an output relevance function which is shown in Figure 9.

The data obtained from temperature plant test for a Fuzzy control applying two consecutive steps is shown in Figure 10.

Besides the Fuzzy control, it was wanted to compare with other types of control, adding PID, simply PID or PID with Fuzzy logic.

Figure 11 shows the curve behaviour applying two consecutive steps using PID control.

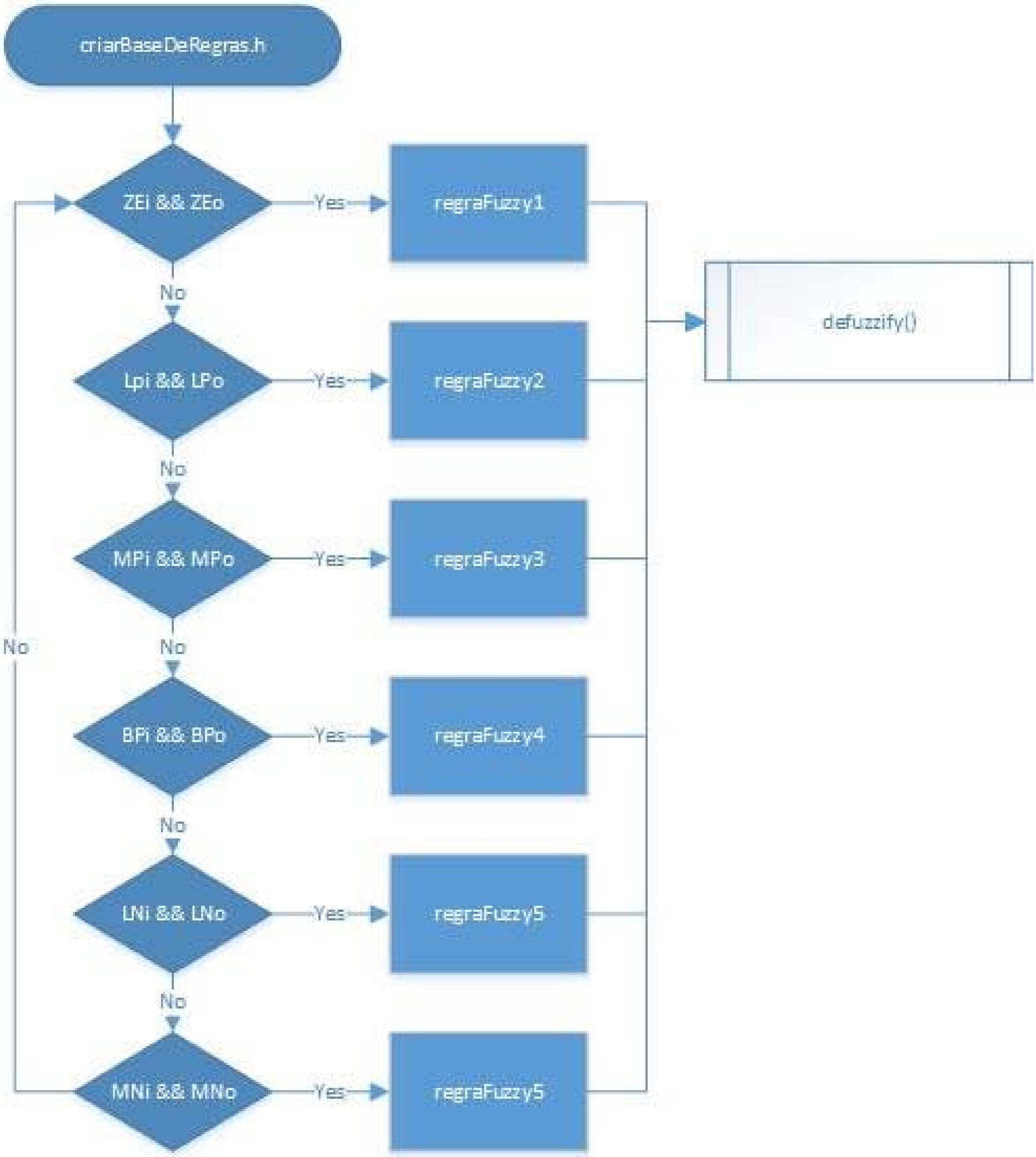

Figure 8. Creating rule base

The procedure for implementing the program is necessary to adjust PID control parameters, and it means K_p, K_i and K_d.

To see the differences or improvements, it has been tested mixing both controls, first Fuzzy and after a PID control.

The results obtained are shown in Figure 12 applying two consecutive steps using Fuzzy and PID logic.

However, it has been proved if it is used a PID first and after a Fuzzy control, Figure 13 shows that after a Fuzzy logic cannot be used after a PID control, because the variable rises until trespassing the set point and does not return close of it.

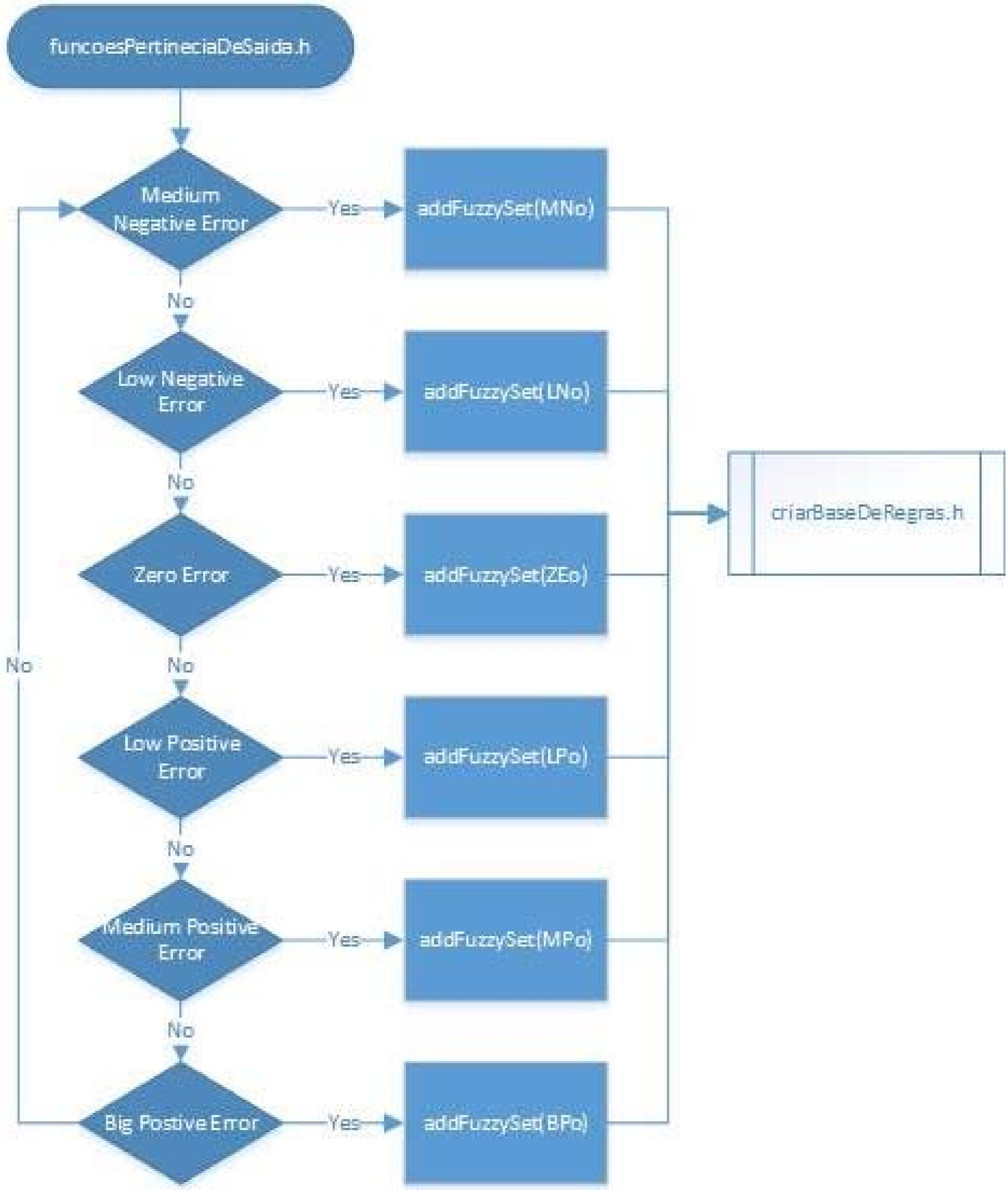

FIGURE 9. Output relevance function

5. **Conclusion.** This project allowed to show the control behaviour we can do not only for a temperature plant, but also many systems.

The project was to determine what type of control is best for generating a rapid response and take control of the system besides being more precise.

Table 4 shows the final results of the control system.

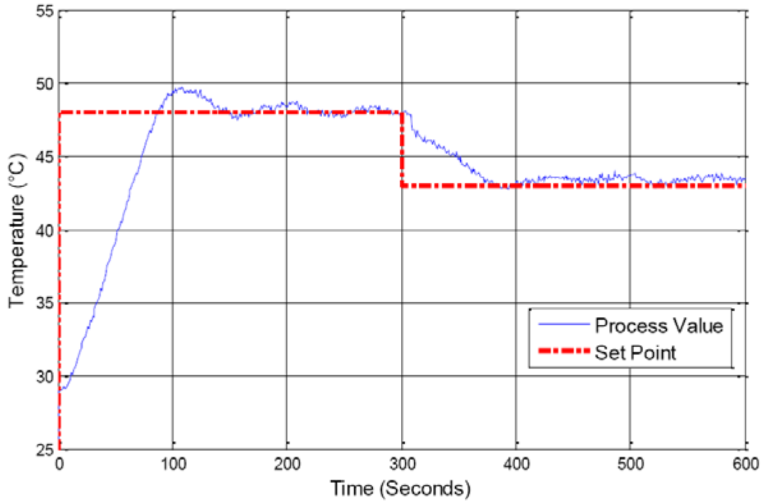

Figure 10. Control with Fuzzy logic

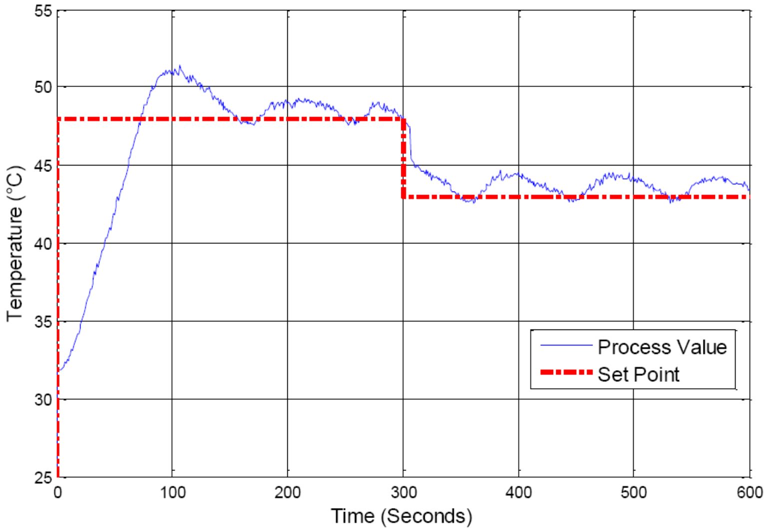

Figure 11. PID control

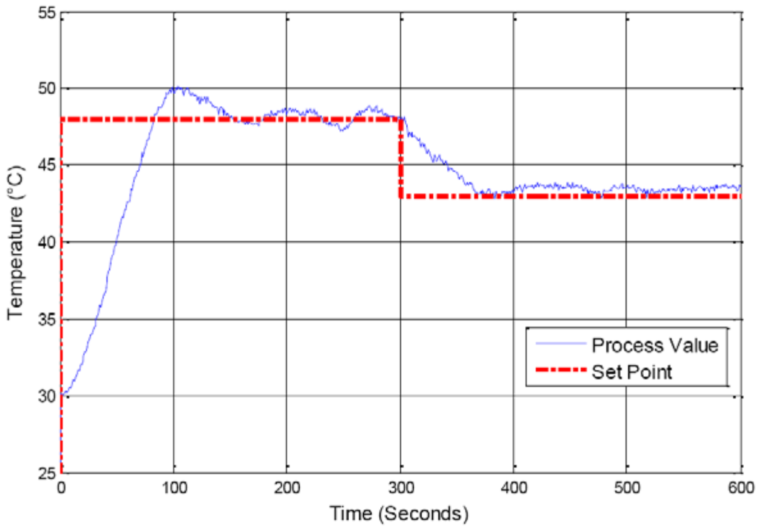

Figure 12. Fuzzy and PID logic

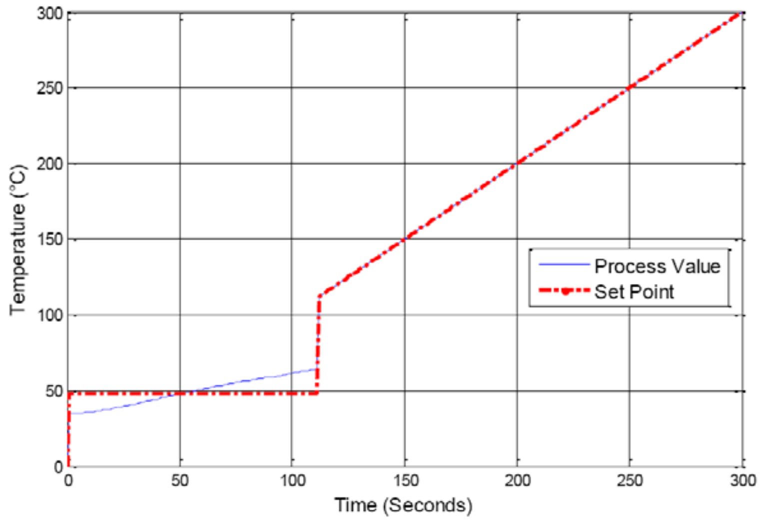

FIGURE 13. Applying a step and a ramp using PID and Fuzzy logic

TABLE 4. Comparative table

COMPARATIVE TABLE				
1st step - 48° 5 min				
Logic	Time to reach the set point [s]	Overshoot [°C]	Stability Time [s]	Error[%]
Fuzzy	49	49.76	51	0.22%
PID	48	51.39	75	0.85%
Fuzzy_PID	47	50.1	53	0.41%
2nd step - 43° 5 min				
Logic	Time to reach the set point [s]	Overshoot [°C]	Stability Time [s]	Error[%]
Fuzzy	47	48.15	62	0.42%
PID	35	48.12	67	0.75%
Fuzzy_PID	58	48.13	58	0.47%

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