A Professional PID Implemented using a Non-singleton Type-1 Fuzzy Logic System to Control a Stepper Motor

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Abstract— *This paper describes the stepper motor position control implemented using a novel non- singleton type-1 fuzzy logic system to update the gains of the professional proportional-integral-derivative controller running on ATMEGA 2560 microcontroller. In this work, three controllers are compared: a) the professional proportional-integral-derivative controller, b) the type-1 singleton fuzzy logic system coupled with the professional proportional-integral-derivative controller, and c) the novel type-1 non-singleton fuzzy logic system coupled with the professional proportional-integral-derivative controller. The experimental results show that the proposed controller has the best performance.*

Keywords— Fuzzy logic, Non-singleton, P-PID, singleton, stepper motor.

I. INTRODUCTION

Currently the use of motors is present around the world on almost any device. Since it was invented it has been investigated to control them in an efficient way. In the modern style of live, it is important to take control of its position, speed and acceleration.

The use of fuzzy logic to improve processes is accepted by several researches. More recently it has been used to adjust the performance of a proportional-integral-derivative (PID) controller, which is acceptable in classical applications.

This paper presents a novel controller that uses the type-1 non-singleton fuzzy logic system tuning the gains of the professional PID (T1 NSFLS P-PID) controller, which was tested with a manufactured fuzzy controller.

In the literature of the singleton fuzzy logic system is used to update the gains of a [1]-[4]. Non-singleton fuzzy logic systems type has been used as controllers [5], [6], and there are several publications available about this theory [7], [8]. As the best knowledge of the authors the type-1 non-singleton fuzzy logic systems have not been used to update the PID controller gains.

There are different techniques for tuning the PID controller gains, some of these techniques include the use of neural networks, genetic algorithms, [9], [10], among others, which are not the scope of this paper.

The performance of the type-1 non-singleton fuzzy logic system coupled with the professional PID (T1 NSFLS P-PID) controller was compared with the P-PID controller and the type-1 singleton fuzzy logic system coupled with the professional-PID (T1 SFLS P-PID) controller. The target of the position of the unipolar stepper motor using an ATMEGA 2560 microcontroller.

In this work Section II explain the basis of the professional PID controller. Section III describes the type-1 singleton fuzzy logic system coupled with the professional PID controller. Section IV explains the design and construction of the proposed type-1 non-singleton fuzzy logic system coupled with the professional PID controller. Section V shows the experiment processes and their results Section VI shows the Conclusions.

II. THE PROFESSIONAL PROPORTIONAL- INTEGRAL-DERIVATIVE

The P-PID controller is a new version of controller used for different processes [11], which is widely accepted in practice, because it includes the proportional-integral and derivative actions, which accelerates the stability and reduces the error.

The P-PID develops under an algorithm of equations (1) and (2). In which the different gains of a classic PID controller (*Kp*, *Ki* and *Kd*) are used. The proportional gain *Kp = Ru / Bp*, *Ru* is the range of the actuator, in most cases it is 0-100% and the *Bp* is the proportional band. *Kp* should adjust with *Bp* because *Ru* is constant. *Ti* is the integral gain that considers the past. The derivative gain *Td* is in charge of the future system and *Tc* is the control period; they may have different samples and thereby take control measures.

Δy(t) is the instantaneous change in the system, and *Ry* is the transmitter range where magnitudes may be different, *Ry = maximum sensor value – minimum value of the sensor.*

The error is calculated using equation (3), in this case $e_n(t)$ is defined as normalized error where $Y_{ref}(t)$ is the reference value and *Y(t)* is the actual or feedback value, this last value generally is obtained using a filter. The structure of this new version is shown in Fig. 1.

$$u(t) = \frac{Ru}{Bp}\left[e_n(t) - \frac{Td\Delta y(t)}{TcR_y}\right] + Int(t) \tag{1}$$

$$Int(t) = Int(t-1) + \frac{TcRu}{TiBp}e_n(t) \tag{2}$$

$$e_n(t) = \frac{Y_{ref}(t) - Y(t)}{R_y} \tag{3}$$

Reading sensors tends to be uncertain due to the existence of different noises. Standard deviation is one of the filters that can be applied, which consists on taking different samples and get the arithmetic meaning. Using (4) is the way to estimate the value of the sensor, where X_i is the sensor reading, and *n* is the number of samples, while more samples, the better the reading.

$$\bar{X} = \frac{\sum_1^n X_i}{n} \tag{4}$$

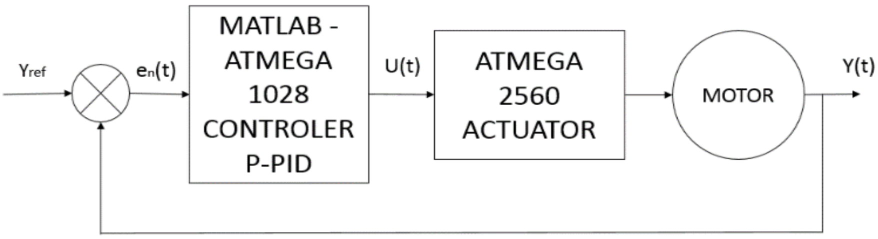

FIG. 1 SCHEME P-PID CONTROLLER.

III. THE TYPE-1 SINGLETON FUZZY LOGIC SYSTEM COUPLED WITH THE PROFESSIONAL PROPORTIONAL-INTEGRAL-DERIVATIVE CONTROLLER

The P-PID controller has many applications, but generally this type of controller is used to control linear systems. In order to successfully implement a controller in nonlinear systems it is required to update their gains depending on the changes that are happening in the system. To update the controller gains, a technique used is to apply fuzzy logic, which it is to intervene in a mathematical way with the design of different rules.

In this work two inputs are used to implement fuzzy logic, these inputs are error (*E*) and error change (*EC*). Adapter diffuse inputs are calculated by (5) and (6).

$$E(t) = Y_{ref} - Y(t) \tag{5}$$

$$EC = E(t) - E(t-1) \tag{6}$$

To apply fuzzy logic in the P-PID, the selection of fuzzy sets was done as shown in Fig. 2 and 3. A Gaussian type fuzzifier is used as shown in (7). Where X_i^* is the value read by the sensor, X_i^L is the mean value of the fuzzy set, σ_i^L is the standard deviation.

$$\mu(A) = \prod_{i=1}^{n} exp\left(-\left(\frac{X_i^* - \bar{X}_i^L}{\sigma_i^L}\right)^2\right) \tag{7}$$

In this type of setting must be adjusted to have the P-PID controller in their optimal gains. The fuzzy logic system reduces or increases these gains to improve the system response. In the equations (8), (9) and (10) shown as the new value of the P-PID gains is introduced. Can observe the procedure in Fig. 4.

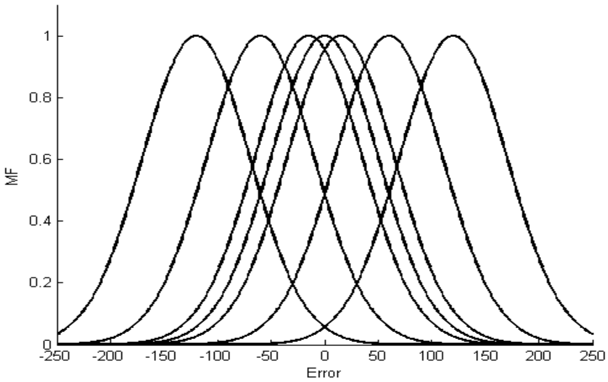

FIG. 2. MEMBERSHIP FUNCTION OF ERROR.

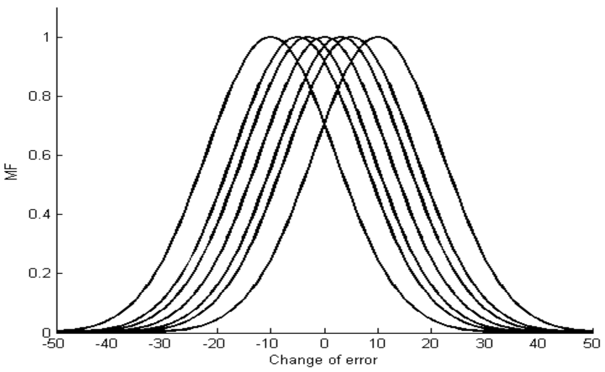

FIG. 3. MEMEBERSHIP FUNCTION OF CHANGE OF ERROR.

$$Bp = Bp' + \Delta Bp \tag{8}$$

$$Ti = Ti' + \Delta Ti \tag{9}$$

$$Td = Td' + \Delta Td \tag{10}$$

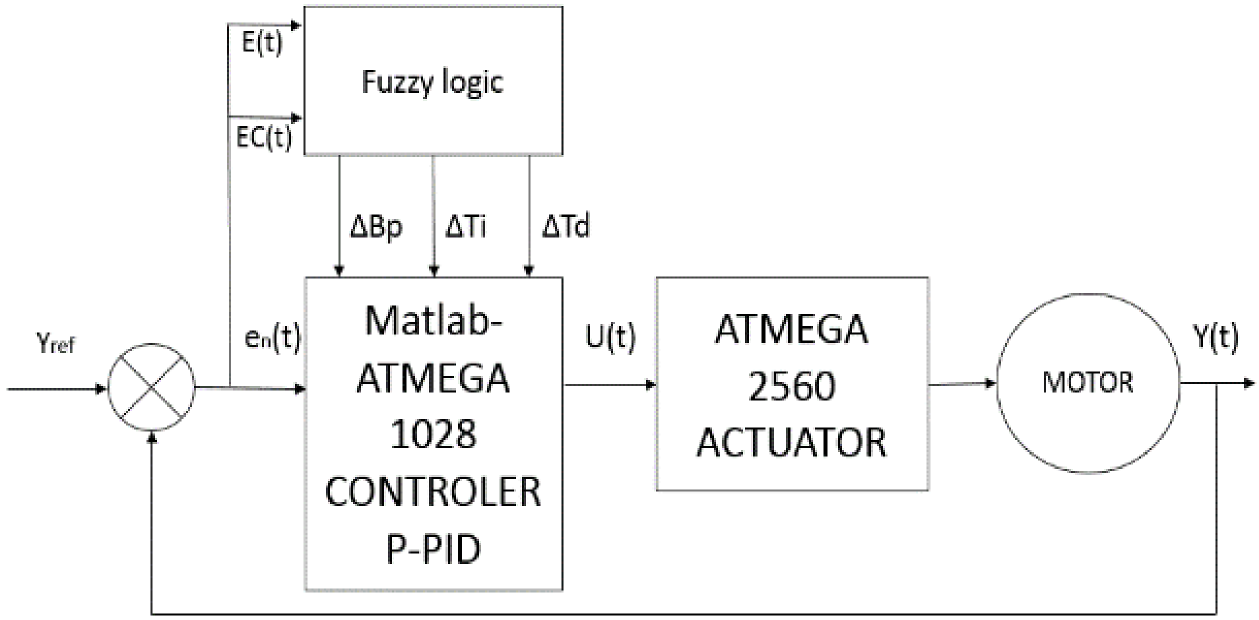

FIG. 4. SCHEME T1 NSFLS P-PID AND T1 SFLS P-PID CONTROLLERS.

Having the fuzzy sets created, the next step is to create the fuzzy rules, into which it must consider how the driver will respond. The rules used for the different gains are shown in the tables I, II and III. The if-then rules can be expressed as:

If the error is “X” and the instantaneous error change is “Y” then the output is “Z”.

Each gain has different behavior; therefore, it must have a different setting. The Rule tables are governed by the following nomenclature: Negative big (NB), negative medium (NM), negative small (NS), zero (Z0), and positive small (PS), positive medium (PM), positive big (PB).

In the P-PID controller, $Kp=Ru/Bp$ gain is constant, therefore the variable to be modified is Bp, but Kp inversely proportional to Bp, thus the adjustment of Bp is the inverse.

TABLE 1
RULES FOR ΔBP

ΔBp		EC						
		NB	**NM**	**NS**	**Z0**	**PS**	**PM**	**PB**
E	**NB**	PB	PB	PM	PM	PS	Z0	Z0
	NM	PB	PB	PM	PS	PS	Z0	NS
	NS	PM	PM	PM	PS	Z0	NS	NS
	Z0	PM	PM	PS	Z0	NS	NM	NM
	PS	PS	PS	Z0	NS	NS	NM	NM
	PM	PS	Z0	NS	NM	NM	NM	NB
	PB	Z0	Z0	NM	NM	NM	NB	NB

TABLE 2
RULES FOR ΔTI

ΔTi		EC						
		NB	**NM**	**NS**	**Z0**	**PS**	**PM**	**PB**
E	**NB**	NB	NB	NM	NM	NS	Z0	Z0
	NM	NB	NB	NM	NS	NS	Z0	Z0
	NS	NB	NM	NS	NS	Z0	PS	PS
	Z0	NM	NM	NS	Z0	PS	PM	PM
	PS	NM	NS	Z0	PS	PS	PM	PB
	PM	Z0	Z0	PS	PS	PM	PB	PB
	PB	Z0	Z0	PS	PM	PM	PB	PB

TABLE 3
RULES FOR ΔTD

ΔTd		EC						
		NB	**NM**	**NS**	**Z0**	**PS**	**PM**	**PB**
E	**NB**	PS	NS	NB	NB	NB	NM	PS
	NM	PS	NS	NB	NM	NM	NS	Z0
	NS	Z0	NS	NM	NM	NS	NS	Z0
	Z0	Z0	NS	NS	NS	NS	NS	Z0
	PS	Z0	Z0	Z0	Z0	Z0	Z0	Z0
	PM	PB	NS	PS	PS	PS	PS	PB
	PB	PB	PM	PM	PM	PS	PS	PB

Equation (11) is used to obtain the output *f(x)*, which calculates the adjustment of the three gains during each control cycle.

$$f(x) = \frac{\sum_{L=1}^{M} \bar{y}^L \left[\prod_{i=1}^{n} exp\left(-\left(\frac{X_i^* - \bar{X}_i^L}{\sigma_i^L}\right)^2\right)\right]}{\sum_{L=1}^{M}\left[\prod_{i=1}^{n} exp\left(-\left(\frac{X_i^* - \bar{X}_i^L}{\sigma_i^L}\right)^2\right)\right]} \tag{11}$$

IV. THE TYPE-1 NON-SINGLETON FUZZY LOGIC SYSTEM COUPLED WITH THE PROFESSIONAL PROPORTIONAL-INTEGRAL-DERIVATIVE CONTROLLER.

This type of controller is the proposed methodology to update the P-PID controller gains, which uses fuzzy logic to update the three gains. Like the T1 SFLS P-PID controller, uses two entries, the error and error change. The representation of this proposal is shown in Fig. 4.

Because both fuzzy controllers operate in a similar manner, fuzzy sets (Fig. 2 and 3) and fuzzy rules (tables I, II and III) presented in the previous chapter are used. *E* and *EC* values are calculated using (5) and (6) respectively.

The equation (12) represents the fuzzyfier used in the proposed controller. The variable a_i represents the standard deviation of the inputs *E* or *EC* that serve as a filter, reducing the uncertainty in the measurements. This variable is an additional setting that has this controller, which can be an advantage with respect to other controllers.

$$\mu B'(y) = max_{L=1}^{M}\left[\prod_{i=1}^{n} exp\left(\frac{-\left(X_i^* - \bar{X}_i^L\right)^2}{\left(\sigma_i^L\right)^2 + (a_i)^2}\right)\right] \tag{12}$$

The equation (13) shows used defuzzifier, which provides the estimation of the P-PID controller gains. Equations (8), (9) and (10) are used to update *Bp*, *Ti* and *Td* gains.

$$f(x) = \frac{\sum_{L=1}^{M} \bar{y}^L \left[\prod_{i=1}^{n} exp\left(\frac{-\left(X_i^* - \bar{X}_i^L\right)^2}{(\sigma_i^L)^2 + (a_i)^2}\right)\right]}{\sum_{L=1}^{M}\left[\prod_{i=1}^{n} exp\left(\frac{-\left(X_i^* - \bar{X}_i^L\right)^2}{(\sigma_i^L)^2 + (a_i)^2}\right)\right]} \tag{13}$$

V. EXPERIMENTS RESULTS

To perform the comparisons between three different controllers, the position of a unipolar stepper motor was controlled, using an ATMEGA 2650 microcontroller. The position of the motor had a performance range from 0 to 300 °, for this reason it must had control in both directions: the L293D integrated circuit and a H bridge to the reverse rotation of the motor was used.

The sending of signals was done using 10 outputs of the microcontroller, with a digital output of 10 bits. An additional output was used to determine the sign of the control signal and with this the engine rotation.

The ATMEGA microcontroller receives the 10 bits digital signal and converts it to decimal value in order to obtain the speed at which the motor rotates.

The test was performed using the three controllers, P-PID, T1 SFLS P-PID and T1 NSFLS P-PID. The normalized error was used to calculate the PID controller output, but the error and the current change of error were calculated to adjust the gains of the fuzzy controllers.

The results to control the position of a stepper motor are displayed in Fig. 5, 6 and 7.

The P-PID controller shows a quick response but has difficulty settling in its reference point. While the fuzzy P-PID controllers can be set in the reference point, both controllers reduce shock, but the T1 NSFLS P-PID controller tends to stabilize faster than the other controllers, in addition to moving more smoothly.

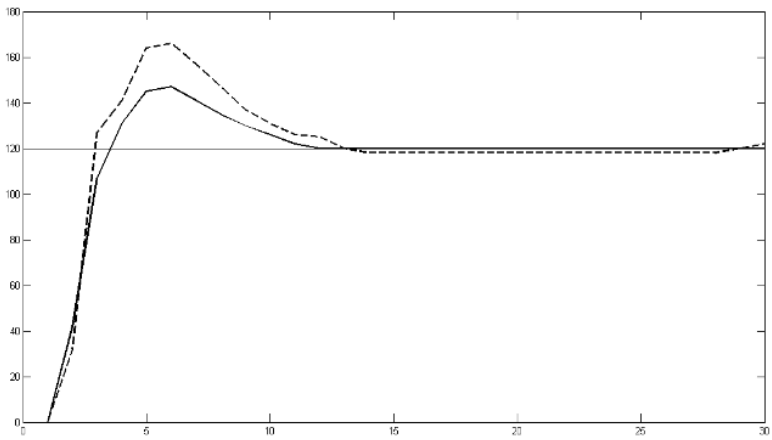

FIG. 5. CONTROLLER'S RESPONSE: T1 NSFLS P-PID (-) AND P-PID (--).

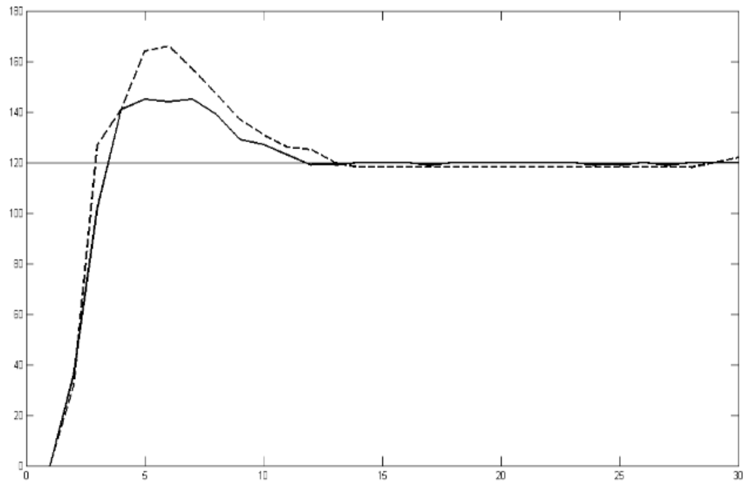

FIG. 6. CONTROLLER'S RESPONSE: T1 SFLS P-PID (-) AND P-PID (--).

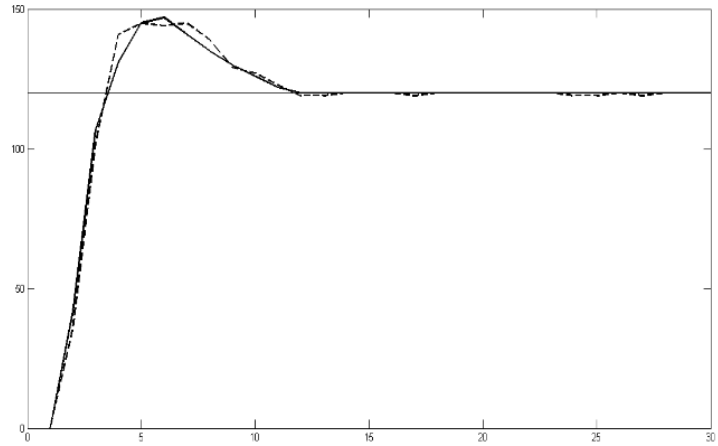

FIG. 7. CONTROLLER'S RESPONSE: T1 NSFLS P-PID (-) AND T1 SFLS P-PID (--).

In the Fig. 8, 9 and 10 show that the T1 NSFLS P-PID controller error reaches zero in the less time.

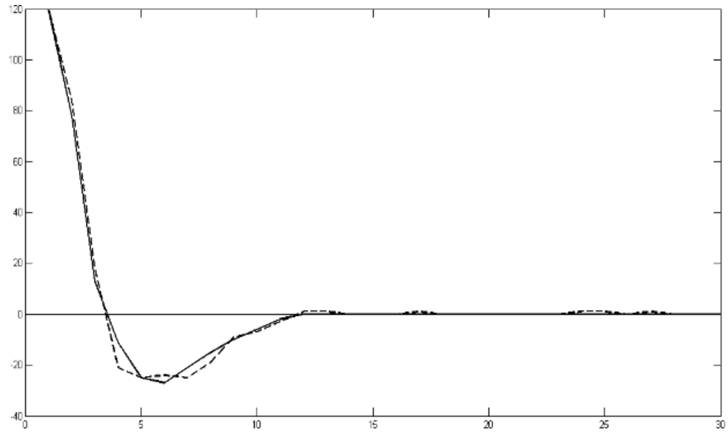

FIG. 8. CONTROLLER'S RESPONSE OF ERROR: T1 NSFLS P-PID (-) AND T1 SFLS P-PID (--).

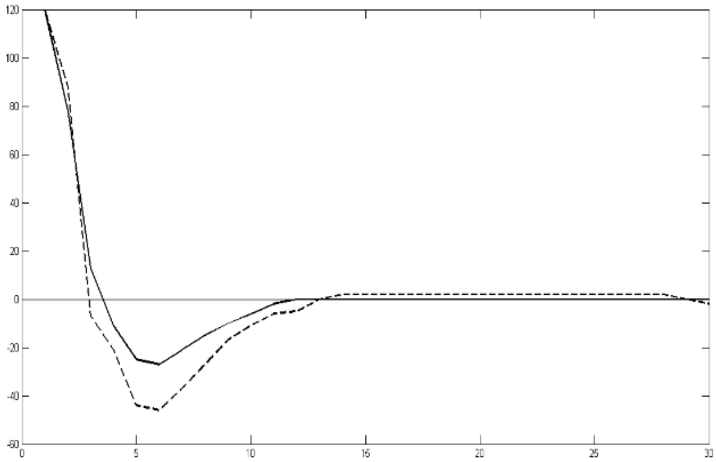

FIG. 9. CONTROLLER'S RESPONSE OF ERROR: T1 NSFLS P-PID (-) AND P-PID (--).

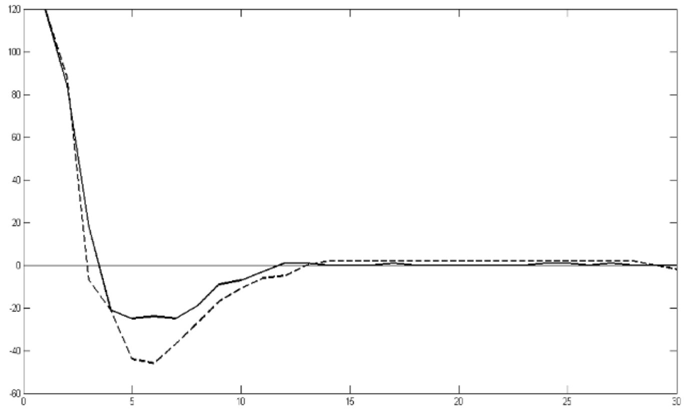

FIG. 10. CONTROLLER'S RESPONSE OF ERROR: T1 SFLS P-PID (-) AND P-PID (--).

VI. CONCLUSION

According to experimental results the proposed hybrid controller, T1 NSFLS P-PID, presents the best performance controlling the position of the stepper motor when is compared with the P-PID controller and T1 SFLS P-PID controller.

The PID controller can have a good answer with its fixed gains, but gains update online Kp, Ki and Kd, improves system response, reducing the overshoot and accelerating the steady state. Fuzzy logic can be adapted in different processes, and in this case being adapted to control the gains of a PID controller, the set point is obtained faster than P-PID controller. For the preparation of the fuzzy rules, it must have a thorough knowledge about the behavior of the controller to be adapted.

In this paper, the use of T1 NSFLS P-PID reduced the overshooting and the stabilization time.

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