Development of a Fuzzy Controller Applied to the Velocity of a DC Motor

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***Abstract*—*Control system designs are becoming increasingly complex due to the operational requirements of current processes. An alternative way to this fact is the application of intelligent systems. This work presents a design of a fuzzy controller tuned by genetic algorithm and applied to the velocity control of a DC motor. For comparative performance purposes, it is designed and applied a conventional PI controller. In general, the fuzzy controller presented a better result compared with the conventional implementation. Results from computer simulations are presented.*

Keywords*—*Fuzzy Controller, PI Controller.

I. INTRODUCTION

Automatic control systems are increasingly present in the industrial environment and have consolidated emphases in academic research. Applications continue to advance as the complexity of control and the need for performance of current processes increases. Control of space vehicle systems and control of innovative manufacturing are examples of areas where automatic control has become essential [1].

Manufacturing systems have been marked with the introduction and modernization of industrial robots that facilitate various activities. For companies specializing in external cleaning of buildings, for example, having drones for cleaning windows, which should be carried out in high places, is something extremely interesting [2].Each day, robots become faster, more flexible, more precise and more economical. This has become possible due to studies in the most varied types of automatic control systems [3].

As explored in [4], the design of a control system is consolidated in function of the identification of an estimated mathematical model that characterizes the process to be controlled. After this step, controller design techniques, such as PID controller tuning are applied. However, the obtaining of the mathematical model can be impracticable, because several unexpected factors dictate this action, for example, the nonlinear dynamics of real processes and the insertion of unexpected perturbations [5].

In the situations where obtaining the estimated mathematical model of the system is impracticable, the intelligent systems are characterized in a valid strategy, mainly when it comesto fuzzy systems, in which the the control strategy is based on linguistic variables and heuristic knowledge of the process to be controlled, which are terms used to define the dynamics of the process to be controlled. An overview of the main concepts of fuzzy control is presented in [6] and [7]. It is important to emphasize that although fuzzy systems do not consider a mathematical formulation with uncertainties associated with each of the parameters they are robust. The errors are compensated by the formulation present in the control system structure itself using the input and output uncertainties of the system [8].

In addition to the mentioned structures, the contributions found in the area of fuzzy controllers also encompass hybrid strategies in which the combination of fuzzy logic and other intelligent systems is contemplated. An example of a hybrid strategy is the situation in which fuzzy controllers have their parameters adjusted from the application of genetic algorithms. These strategies demonstrate satisfactory performances in recent investigations, such as: [9] presents a comparison with a conventional PI controller when applied to power control in a given industrial environment; in [10] it is approached an application of such a strategy for the acceleration control of an autonomous vehicle in order to minimize the start situations of the vehicle; in [11] we demonstrate the use of these controllers to control the speed of a DC motor.

In general, several applications of fuzzy control strategies can be evidenced in field research. In [12] the authors expose the application of a Fuzzy-PD controller to perform the control of a pneumatic manipulator of a microscope, in order to control the distance between the test specimen and the equipment.In [13] a drone is controlled through an intelligent fuzzy controller. In the contributions of [14], it is proposed a methodology for the tuning of gains of a Fuzzy-PI controller to perform a temperature control. Similarly, the work presented by the authors [15] presents an online tuning method of Fuzzy-PID controllers. A comparison between the structure of a conventional PID controller and the strategy of a Fuzzy-PID controller is presented in [16].

Based on the information presented, the present article proposes the use of a Fuzzy-Incremental controller, in which its gains are attributed through a genetic algorithm, to accomplish the speed control of a servomechanism, more specifically of a DC motor that composes a didactic tool of the manufacturer DatapoolEletrônicaLtda, model 2208. In order to validate the proposal, the performance of the fuzzy controller is compared with the performance of a conventional PI controller, which is designed from the survey of the process transfer function and applied the appropriate techniques for the respective tuning of the gains.

This paper is organized as follows. Section 2 presents the main aspects of servomechanisms and the didactic tool used. Then, in Section 3, an approach is presented about the main fuzzy control strategies with a focus on the method considered in this work, as well as the method used for the tuning of the conventional PI controller used for the comparison, whereas in the Section 4 are presented the results of computational simulations. Section 5 discusses the main conclusions of this proposal.

II. FUNDAMENTALS ABOUT THE SERVOMECHANISM USED AND GENERAL ASPECTS OF THE TEACHING MODULE

The servomechanism used in this work is part of a teaching module developed by DatapoolEletrônicaLtda, model 2208, in which one can investigate and apply process control techniques to control the speed and angular position of DC motors. It consists of a servo-potentiometer as an angular displacement transducer. To measure rotation, a tachometer is used which provides a voltage signal proportional to velocity in the range of 0 to 5 V. This didactic tool is shown in Fig. 1 [17].

Fig. 1: Datapool module, model 2208.

The voltage range used to generate the angular movement of the servomotor is - 5 to + 5 V where negative values provide a counterclockwise rotation while positive values imply a clockwise rotation. In this way, it was decided to restrict the rotation only in the clockwise direction (0 to 5 V) because abrupt variations between positive and negative voltages (and vice versa) can damage the mechanical system of the module. The output voltage of the module tachometer implies a direct relationship with the angular velocity of the servomotor, that is, 1 V corresponds to 1 rad / sec.

Based on the module definitions presented and from a process control point of view, the manipulated and controlled variables correspond, respectively, the voltage applied to the servomotor and the speed measured by the tachometer. This statement is exemplified by the diagram shown in Fig. 2.

Fig. 2: Block diagram of the process.

For computational simulation purposes, it was necessary toaccomplish the lifting of the transfer functionof the servomotor considered. Techniques for this procedure are defined in the literature as systems identification. It is worth noting that, in practical terms, knowledge of the transfer function is not relevant to the fuzzy controller design of this proposal.

2.1 Identification of the Servomechanism System

Identification of a system is the determination of the estimated mathematical model that represents the main aspects of the dynamics of a system for a particular use: diagnosis, supervision, optimization and control [18].

The models can be characterized by transfer functions of first or second order. In this work, the estimated process model is represented in(1), where K is the static gain of the process, L is the transport delay and T is the time constant [1].

$$G(s) = \frac{Ke^{-Ls}}{Ts+1} \quad \ldots\ldots (1)$$

The identification method was Broída [19], which presents the response of the first order system on a higher order curve obtained experimentally, in order to find the parameters K, T and L , where the latter two can be obtained by means of the expressions (2) and (3).

$$T = 5\,(t_2 - t_1) \quad \ldots\ldots (2)$$

$$L = 2{,}8t_1 - 1{,}8t_2 \quad \ldots\ldots (3)$$

Based on the parameters presented, the identification of the transfer function of the system to be controlled, defined in the literature as G (s), was accomplished from the applicationof a unit step 1 V at the servomotor input. The system response data were collected and then analyzed to obtain the parameters K, T and L. The transfer function G(s) found is presented in (4).

$$G(s) = \frac{1{,}378}{0{,}1451s+1} e^{-3{,}12e-5s} \quad \ldots\ldots (4)$$

Based on the transfer function obtained, it was possible to implement the control strategies considered. The computational simulations were performed using Matlab software and the Simulink tool.

III. FUZZY CONTROL STRATEGY APPLIED TO SERVOMOTOR CONTROL

The option of using fuzzy logic to establish control strategies is due to the increasing complexity of the processes currentlyfound in industrial demand.

As stated in [20], in some cases PID control may become inadequate, as in the control of higher order processes with oscillatory characteristics or multivariate systems. The factors cited tend to make it difficult to estimate the mathematical model. On these occasions, the implementation of fuzzy control is a valid option.

Fig. 3 shows a fuzzy controller added to a plant. It is observed that the controller admits as input the reference signal and the process output signal, resulting from the feedback of the system. In many cases, this type of control structure uses the reference signal, defined by the process operator, for calculating the error signal, resulting from the difference between the reference and the output signal.

In [21] are evidencedsome possible fuzzy controller structures that are: Fuzzy-P, Fuzzy-PD, Fuzzy-Incremental, and Fuzzy-PD + I. The Fuzzy-Incremental and PD + I structures represent, respectively, analogies to the classical PI and PID controllers.This fact assists in the elaboration of rules of the fuzzy controller because the gains linked to such structures reflect in a control implication similar to the Kp, Ki and Kd gains of the conventional PID controllers.

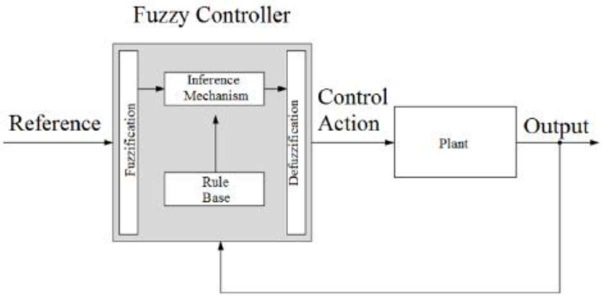


Fig. 3: Block diagram of a generic fuzzy control structure.

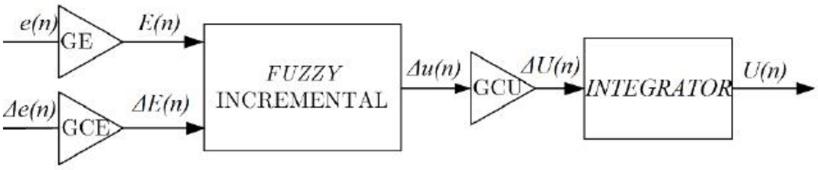


Fig. 4: Fuzzy-Incremental.

In this work it is considered the design of a Fuzzy-Incremental controller in which the gains are adjusted through a genetic algorithm.

3.1 Fuzzy-Incremental

The operational principle of this controller is based on the inputs related to the error and error variation, given by e (n) and Δe (n), and multiplied by the gains GE and GCE, respectively. Its output is represented by an increment given by Δu (n) or ΔU (n), when multiplied by a gain GCU.

The block diagram that represents the Fuzzy-Incremental structure is presented through Fig. 4. It is observed that the incremental output is represented by an integrator term, which can be approximated by a sum of all the previous increments, being called the rectangular approximation [22].

The referred fuzzy control strategypresents a dynamic similar to the conventional PI controllers.The relations of gains (5) and (6) are confirmed for this structure [21].

$$GCE*GCU=Kp \quad \ldots\ldots (5)$$

$$\frac{GE}{GCE} = \frac{1}{Ti} \quad \ldots\ldots (6)$$

The implementation of this controller for the velocity control of the servomotor considered in this work can be exemplified by means of Fig. 5.It is observed that there are the variables r (n) and y (n) which represent, respectively, the control reference value and the output of the system.Also the possibility of inserting noise was considered, in order to verify the performance of the system against unexpected situations.

For the definition of pertinence functions, the following linguistic variables were considered: PG: large positive; PM: medium positive; PP: small positive; P: positive; Z: zero; N: negative; NP: small negative; NM: medium negative and NG: large negative. The universe of discourse of error and error variation was defined in the range of -5 to +5, which represent positive and negative errors. For the incremental output, the domain was assigned -1 to +1.

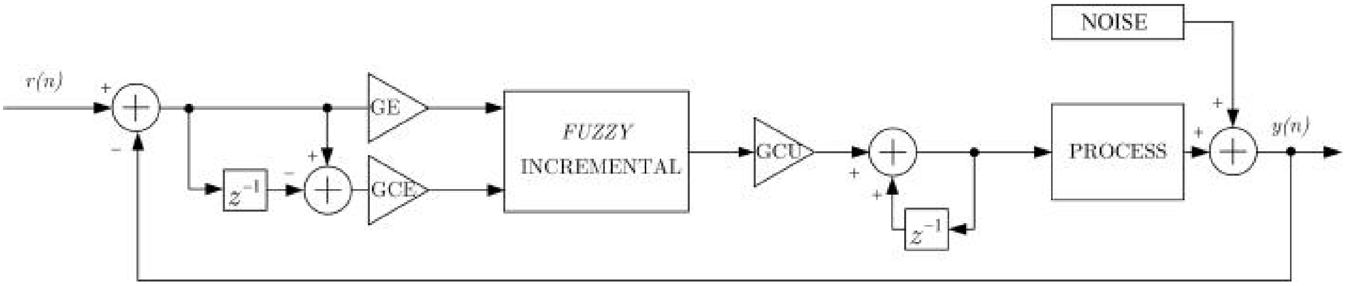
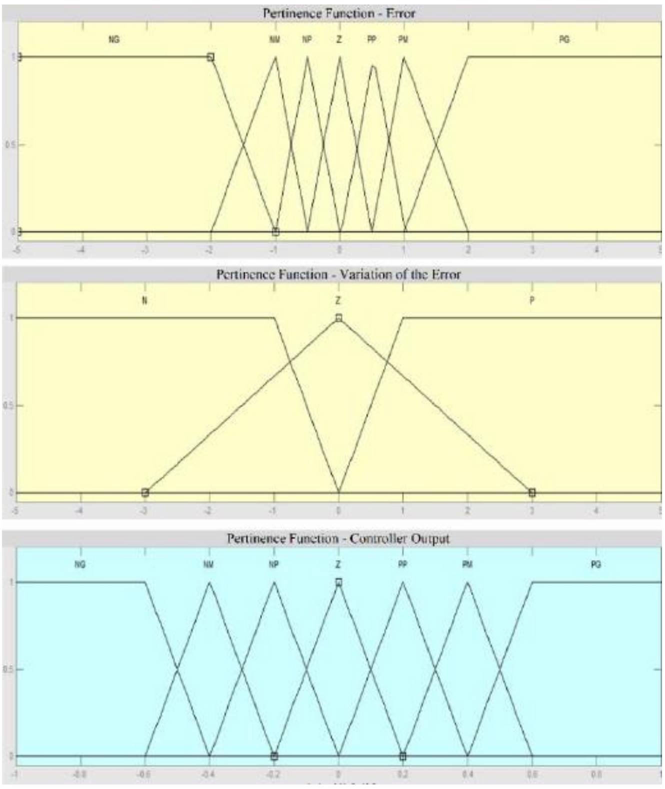


Fig. 5: Fuzzy-Incremental controller implementation diagram.

The pertinence functions are presented by means of Fig. 6, while the rules are shown in Table 1. It is important to emphasize that these definitions were attributed to heuristic knowledge of the process.


Pertinence Function - Error

Pertinence Function - Variation of the Error

Pertinence Function - Controller Output

Fig. 6: Pertinence Functions.

Table 1: Fuzzy-Incremental controller rules.

Δe\e	PG	PM	PP	Z	NP	NM	NG
P	Z	Z	Z	NP	NM	NG	NG
Z	PG	PM	PP	Z	NP	NM	NG
N	PG	PG	PM	PP	Z	PM	PG

The GE, GCE and GCU gains were adjusted using the genetic algorithm, which is characterized by a metaheuristic optimization technique [23]. This step was considered from the following procedures:

a) Definition of the initial population: each individual was considered as a set of three parameters. Random values were initially applied to the gains and a unit reference was applied to collect the system response data. This procedure was repeated for each individual of the initial population.

b) Definition of the fitness function: in order to evaluate each individual, a fitness function was defined to penalize those that caused a slow response and with high overshoot. To exemplify, consider the expression (7), where the percentage performance of the i-th individual is evaluated. *tr* is the time the response took to reach the reference value for the first time, *tsim*is the considered time of simulation, *tymax* is the time at which there was the maximum output value, *ymax* is the maximum value output and ref is the reference value used.

$$fit\,(i) = \left[1 - \left(\frac{t_r}{tsim} + \frac{t_{y\,max}}{tsim}\right)\right] - \frac{y_{max} - ref}{5} \text{........}(7)$$

c) Selection of individuals for reproduction: the selection of the roulette type was chosen.

d) Application of the crossover: the crossing of the individuals was performed by the conventional method, in which the offspring receive parcels of each parent chromosome. Subsequently, the mutation procedure was applied, in which the nth gene of the son to be mutable receives the mean among the nth genes of the parent chromosomes.

e) Choice of the best individual: in the end, the individual chosen was the set of gains that implied the highest result of the fitness function.

f) The gains found in this way were: GE = 0, 5, GCE = 1, 62 and GCU =1,4.

For performance comparison purposes, a conventional PI controller was designed based on the transfer function obtained for the simulation. The PI control action combines the characteristics of proportional and integral control in the same controller and can be represented by equation (8) [1], where *Kp* is the proportional gain, and *e(t)* is the error, *Ti* is the integrative time.

$$\frac{U_{(s)}}{E_{(s)}} = K_P\left(1 + \frac{1}{T_i s}\right)\text{......................................}(8)$$

The method of tuning this controller was approached using the technique known as Cohen-Coon [24], where the gains were: *Kp* = 0,3436 and *Ti* = 8,0244.

IV. RESULTS

The results presented in this section refer to the application of the fuzzy controller tuned via the genetic algorithm and the conventional PI controller.

Three types of experiments were accomplished for the performance analysis. In the first case, it was considered a fixed and unitary reference, in order to evaluate the velocity of response of the controllers, as well as the stabilization of the system.Subsequently, for the second case, the insertion of a disturbance signal into the system was considered after its stabilization and with random amplitude.The disturbance mentioned may represent an unexpected variation in the voltage applied to the actuator. In the third case, the variation in references was considered, including positive and negative steps.

The results are presented in order to make possible the analysis of both the response of the system and the control action employed in the actuator.

Figures 7, 8 and 9 present the results as a function of the three types of experiments described above, respectively. It is possible to notice that for all cases, the Fuzzy-Incremental controller provided a faster stabilization of the response, even spending half the stabilization time of the PI controller in the first case. There was a substantial reduction of the overshoot to the Fuzzy-Incremental controller in the observed cases.In addition, the response of the actuators with the conventional PI controller clearly shows greater variation than the Fuzzy-Incremental controller.

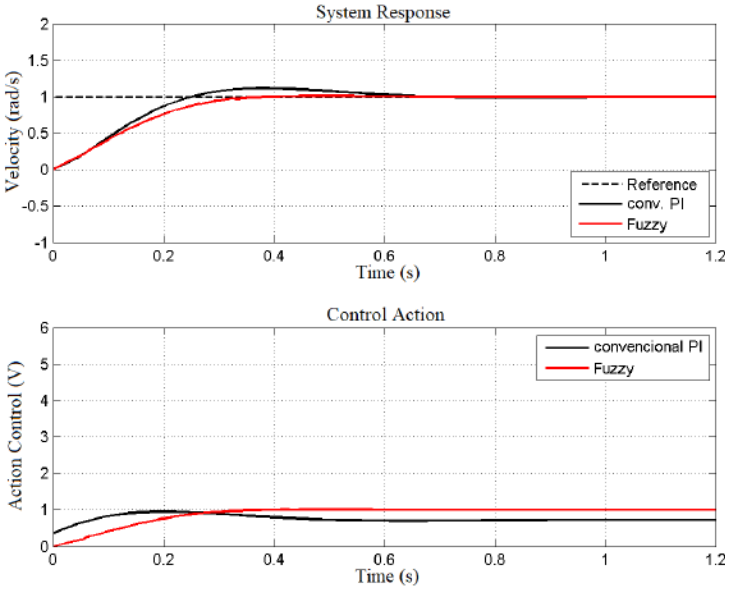


Fig. 7: Experiment 1 – fixed reference.

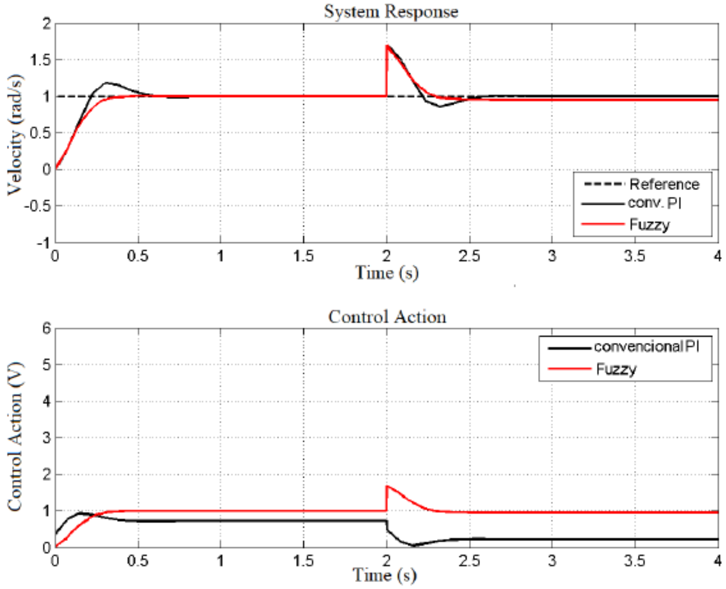


Fig. 8: Experiment 2 –application of disturbance.

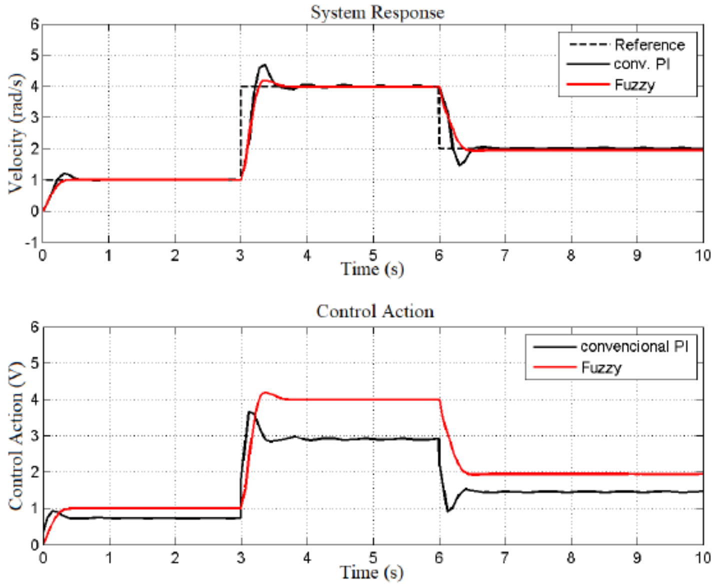


Fig. 9: Experiment 3 – variations in the reference.

V. CONCLUSIONS

In this work a fuzzy control strategy applied to a speed control of a DC motor was presented. It is the Fuzzy-Incremental structure in which its gains were tuned by genetic algorithm.

For comparison purposes, a conventional PI controller was designed for this control purpose, where the gains were attributed according to the Cohen-Coon method.

In general, the fuzzy control presented a better response when compared to the conventional controller. There was a reduction of the overshoot and a faster stabilization of the system.

These results demonstrate that the processes to be controlled that present a dynamic that makes it difficult to obtain the transfer function can be controlled by means of fuzzy strategies and, consequently, modeled from a rule base that composes the heuristic knowledge of the process.

Another factor to be highlighted is the way in which the gains of the fuzzy controller were obtained, since the adjustment of the fuzzy controllers is often done empirically. Such adjustments are intended to fine-tune the inadequacies provided by the rule base initially defined.

As future work, it is suggested to analyze the criterion that quantifies performance properties reconciled the robustness in the two controllers through the analysis of integral of time multiplied by the absolute value of error (ITAE).

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