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Tuning the Fuzzy Controller for Speed Control of the DC Motor

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Abstract— **In this paper, it is developed the fuzzy controller for speed control of the DC motor. The obtained results of tuning the controller were compared with maximum stability degree method with iterations and genetic algorithm. To verify the efficiency of the developed fuzzy controller the computer simulation was done. The algorithm of tuning the fuzzy controller was designed according to the error and the rate of change of the error signal, so that performance of the closed-loop step response to be satisfied.**

Keywords—fuzzy controller; PID controller; system performance; automatic control system; maximum stability degree method with iterations

I. INTRODUCTION

The control of the processes is usually used for production in series. The most used control algorithm in industrial applications is the PID controller and its variation P, PI, PD, due to simplity and good performance that they offer to the automatic control system. The PID controller consists from three terms: P – the proportional component (present error), I – the integral component (past errors) and D – derivative component (future variation of the error) [3-6].

However, in some cases the PID controller has a suboptimal performance in the industrial applications. For the last decades, there are developed a lot method for tuning the PID control algorithm and its variation as P, PI, PD controller. These methods and algorithms are mostly insufficient to synthesize the PID controller for a nonlinear process. Some techniques and algorithms that are used to tune the PID controller involve the implication of the operator or engineer. The fuzzy logic for the last period becomes so popular for different industrial domains and achieved a certain degree of success in design the fuzzy controllers. The operation of the fuzzy controller is based on the transfer of experience of the qualified operators. Due to the success of fuzzy controllers, fuzzy PID controllers have been studied in the last ten years and wide used in industrial applications. Also, the application of autonomous or intelligent fuzzy PID controllers has become popular recently, and many researchers have explored the research in the field of self-tuning fuzzy PID controllers. For example, self-tuning fuzzy PID controller has been applied for load and frequency control in energy conversion, heating, ventilation and air conditioning, etc. The self-tuning fuzzy PID controller is a controller with self- learning module.

An automatic system with the fuzzy controller is presented in Figure 1 [7-8].

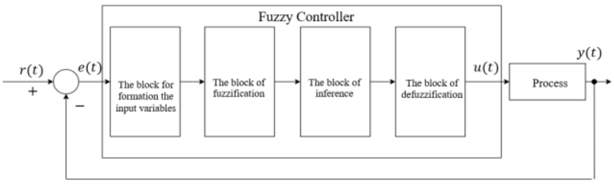

Figure 1. Block scheme of the automatic control system with fuzzy PID controller.

The fuzzy controller has four main components as shown in the Figure 1:

- The block for formation the input variables, in which is defined the input and output variables for fuzzy controller.
- The fuzzification block is the block that helps to convert inputs to language variables. It allows the conversion of crisp numbers into fuzzy sets. The inputs measured by the sensors and passed to the control system for further processing.
- The interference block is the decision-making block, it represents the core of the fuzzy controller, that materializes the human decision-making process.
- The defuzzification block is performed to convert the fuzzy sets into a crisp value. There are many types of techniques for defuzzification. So this block transforms

the fuzzy values of the interference block into well-determined values. The values resulting from the defuzzification are subjected to the inverse normalization operation in order to be brought into an interval close to the range of command quantities [7-8].

In this paper, it is proposed to design the fuzzy controller for speed control of the DC motor, according to the imposed performance.

II. Description of the Designed System

It was used the DC motor FK130SH motor for testing several reaction wheels, that is controlled by the STM32F303K8 microcontroller. The system was implemented based on the NUCLEO-F303K8 platform from ST Microelectronics and the reaction wheel is coupled directly to the motor, Figure 2. As the speed sensor, the EE-SX4235A-P2 transmissive photomicrosensor is used [2].

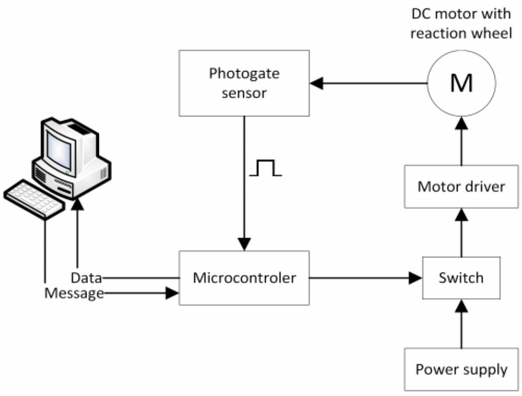

Figure 2. Block diagram of the designed system [1].

It was done the experimental identification of the mathematical model of the DC motor, using the System Identification Toolbox from Matlab. For experimental identification, it was raised the experimental curve of the variation the DC motor speed, for the reference speed of 7330 rpm, Figure 3.

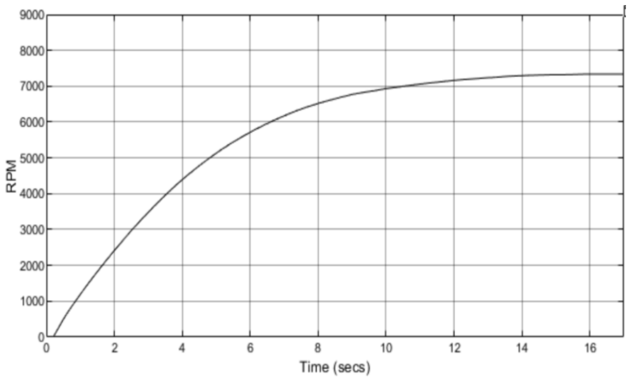

Figure 3. Experimental curve.

The experimental curve of the speed variation of the DC motor, it was approximated with the model of object with inertia second order [1-2]:

$$H(s) = \frac{k}{(T_1 s+1)(T_2 s+1)} = \frac{1.0069}{3.1695s^2 + 5.0289s + 1}. \quad (1)$$

III. Synthesis of the Fuzzy Controller

The fuzzy controller is a controller with two inputs: the error e and the derivative of the error $\grave{e}$ and a single output, which represents the input variable of the process, denoted by the u. The universe of discourse of variables $e, \grave{e}$ and u are $E \subset R$, $\grave{E} \subset R$ and $u \subset R$ respectively. The linguistic values of e and $\grave{e}$ are set on the following sets $A_i(i \in I = [-m, \dots, -2, -1, 0, 1, 2, \dots, m])$ and $B(j \in J = [-n, \dots, -2, -1, 0, 1, 2, \dots, n])$.

If e is A_i and $\grave{e}$ is B_j then u is u_{ij}, where $U_{ij} \in u(i \in I, j \in J)$ is the clear value instead of a fuzzy subset, u_{ij} are not immediately different from each other. The fuzzy controller with such control is called a clear-type fuzzy controller. At a time instant , the observation values e and $\grave{e}$, are shown, which correspond to the system error and the rate of change of the error, respectively. Then the truth values of A_i and B_j are $A_i(e)$ and $B_j(\grave{e}), (i \in I, j \in J)$. Using the sum-of-product inference method, the truth value of the antecedent part of a fuzzy control rule will be [8]:

$$f_{ij} = A_i(e)B_j(\grave{e})(i \in I, j \in J).$$

Reasoning from the antecedent part to the consequent part will generate a fuzzy subset conclusion which is called as C, C will be a discrete fuzzy subset with a finite number of points.

$$C = \{\frac{f_{ij}}{u_{ij}} | i \in I, j \in J\}.$$

Applying the centre of gravity method to defuzzify the fuzzy set C, the actual controller output is obtained:

$$u = \frac{\sum_{i,j} f_{ij} u_{ij}}{\sum_{i,j} f_{ij}}.$$

Table I shows the fuzzy rules of the system, based on which the operating conditions of the system are realized [8].

TABLE I. THE BASE OF THE FUZZY RULES

E / ΔE	NL	NM	NS	ZR	PS	PM	PL
NL	NL	NL	NL	NM	NS	ZR	PS
NM	NL	NL	NM	NS	ZR	PS	PM
NS	NL	NM	NS	ZR	PS	PM	PL
ZR	NM	NS	ZR	PS	PM	PL	PL
PS	NS	ZR	PS	PM	PL	PL	PL
PM	ZR	PS	PM	PL	PL	PL	PL
PL	PL	PL	PL	PL	PL	PL	PL

The rules that were entered using the Fuzzy Logic Toolbox from MATLAB are represented in Figure 4.

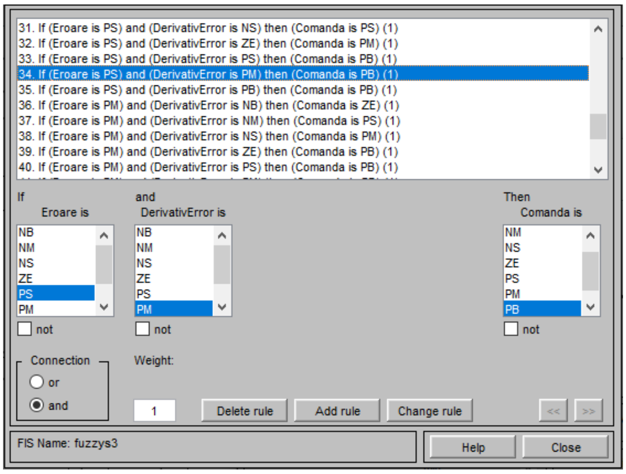

Figure 4. The rules generated based on the rule table from MATLAB.

The rule visualization is presented in the Figure 5.

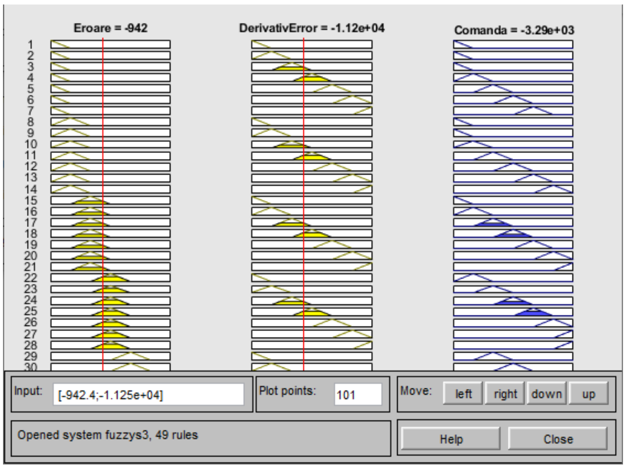

Figure 5. Graphical representation of fuzzy rules.

The membership functions for the input and output variables are presented in the Figure 6.

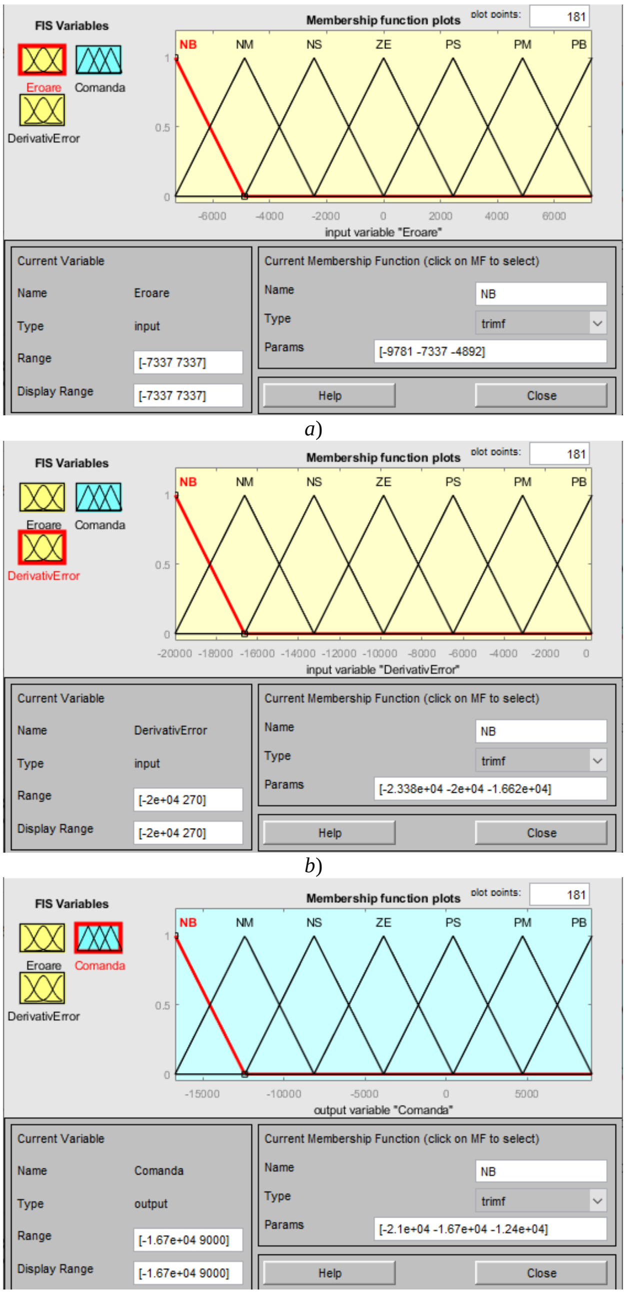

Figure 6. The membership functions: *a*) error signal; *b*) rate of change of the error signal; *c*) command signal.

The obtained results of tuning the fuzzy controller are presented in the Figure 7. The results were compared with maximum stability degree method with iterations and genetic algorithm.

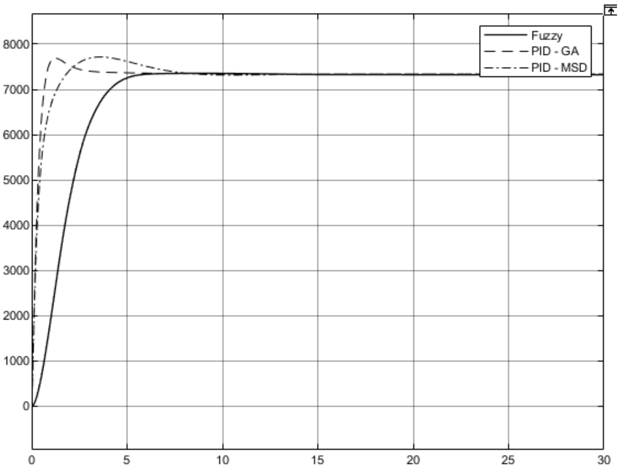

Figure 7. The transient responses of the control system with PID controller.

The obtained performance of the automatic control system are presented in the Table II.

TABLE II. PERFORMANCE AUTOMATIC CONTROL SYSTEM

No	Controller	Method	Performance of the system			
			t_r	t_s	σ	λ
1	PID	GA	0.55	2.00	3.99	1
2	PID	MSD	0.93	5.039	7.83	1
3		Fuzzy controller	4.2	4.2	-	-

IV. CONCLUSIONS

In this work, it was proposed to design the fuzzy controller for speed control of the DC motor. As DC motor it was proposed to use the FK130SH motor and the system was implemented based on the NUCLEO-F303K8 platform from ST Microelectronics.

It was realized the experimental identification of the mathematical model, that approximates the dynamics of the DC motor by the transfer function with inertia second order. It was done the comparison of the obtained results with maximum stability degree method with iterations and genetic algorithm. The fuzzy controller permitted to obtain critically damped step response of the automatic control system.

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REFERENCES

[1] V. Melnic, I. Cojuhari, "Experimental Identification of the Mathematical Model of the DC Motor based on the Genetic Algorithm," In: Proceedings of the of the Workshop on Intelligent Information Systems WIIS2020, December 04-05, Chisinau, Republic of Moldova, pp. 109-114.

[2] V. Melnic, I. Cojuhari, "Estimation of the Mathematical Model of the DC engine coupled with a reaction wheel.," In: ROMAI Journal, v.14, no.2(2018), pp. 103–112.

[3] Ahmed Mohammed, Tahir Nura, Zimit Aminu, Idi Musa, Abubakar Kamal, Jalo Salihu, "Improved PID Controller for DC Motor Control Improved PID Controller for DC Motor Control," In: IOP Conference Series: Materials Science and Engineering. 1052. 10.1088/1757-899X/1052/1/012058.

[4] Manoj Kushwah, Ashis Patra, "Tuning PID Controller for Speed Control of DC Motor Using Soft Computing Techniques-A Review," In: Advance in Electronic and Electric Engineering. ISSN 2231-1297, Volume 4, Number 2 (2014), pp. 141-148.

[5] Ashwaq Abdulameer, Marizan Sulaiman, MSM Aras, Dawood Saleem, "Tuning Methods of PID Controller for DC Motor Speed Control," In: Indonesian Journal of Electrical Engineering and Computer Science Vol. 3, No. 2, August 2016, pp. 343-349.

[6] Mohammed E. El-Telbany, "Tuning PID Controller for DC Motor: An Artificial Bees Optimization Approach," In: International Journal of Computer Applications (0975 – 8887) Volume 77– No.15, September 2013, pp. 18-21.

[7] Erenoglu Isin, Eksin Ibrahim, Yesil Engin, Guzelkaya Mujde, "An Intelligent Hybrid Fuzzy PID Controller," In Proceedings 20th European Conference on Modelling and Simulation, 2006. 10.7148/2006-0062.

[8] S. Choopra, R. Mitra, V. Kumar, "Fuzzy Controller: Choosing an Appropriate and Smallest Rule Set ," In International Journal of Computer Cognition , Vol. 3, No. 4, 2005.