Time-Response Optimization Based on Fuzzy Logic Controller for a Second Order Filter

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ABSTRACT

This paper deals with the design of a fuzzy logic controller with 9-rules and 25-rules through a Mamdani fuzzy scheme. Fuzzy logic controller is designed on the error of the controlled variable and the change of the error. The proposed scheme is tested for an RC second-order system with different fuzzy rules. The proposed controller is designed using a very simple control rule–base having 9-rules and 25-rules with triangular membership functions. Simulation results justify the effectiveness of the proposed scheme. The simulation results under MATLAB environment has predicted better performance with fuzzy controller with 25-rules than the 9-rules. In results, Conventional PID Controller and Fuzzy Logic Based Controller implemented on RC second-order system. The step input is taken as the reference input to obtain the transient response of the system. The target of this paper is making the transient response of the second-order filter will follow the reference input without steady state error.

Keyword: - *Fuzzy Logic Controller, Second-Order, and System Identification.*

1. INTRODUCTION

PID Control schemes based on classical control theory are widely used in industry because of simple structure, reliable operation and near optimal performance. Thus, PID controller is the most common form of feedback. The controllers consist of many different forms. However, an important aspect of PID Controller is that they need to be tuned properly. Offline method such as Ziegler- Nichols method is used to tune the PID or an expert human operator can manually tune the PID parameters.

PID Controller primarily comprises of three parameters which influence the controller action are Proportional gain Derivative gain and Integral gain. The proportional gain block generates a control signal which is proportional to the error. Derivative block generates a control signal depending on the rate of change of error. Integral block generates a control signal depending on the summation of past mistakes [1, 2]. Unlike PD controllers, PID-type FLCs are suitable mainly for systems and systems with large dead time.

After being mostly viewed as a controversial technology for two decades, fuzzy logic has finally been accepted as an emerging technology since the late 1980s. This is largely due to a wide array of successful applications ranging from consumer products, to industrial process control, to automotive applications [3]. Fuzzy logic is closer in spirit to human thinking and natural language than conventional logical systems [4]. Classical control theory is based on the mathematical models that describe the physical plant under consideration. The essence of fuzzy control is to build a model of human expert who is capable of controlling the plant without thinking in terms of mathematical model [5]. Fuzzy systems are very useful in two general contexts:

1. In situations involving highly complex systems whose behaviors are not well understood.

2. In situations where an approximate, but fast, solution is warranted [6].

The second-order we used in this paper is shown in figure 1 and its mathematical model as the following:

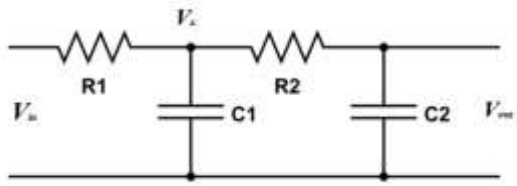

Fig -1: Second Order RC Filter

Apply Kirchhoff's Current Law (KCL) for V_o

$$\frac{v_o - v_x}{R_2} + SC_2 v_o = 0$$

$$v_x = v_o(1 + SR_2C_2)$$

Apply Kirchhoff's Current Law (KCL) for V_x

$$\frac{v_x - v_i}{R_1} + \frac{v_x - v_o}{R_2} + SC_1 v_x = 0$$

$$R_2(v_x - v_i) + R_1(v_x - v_o) + SR_1R_2C_1v_x$$

$$v_x(R_1 + R_2 + SR_1R_2C_1) - R_2v_i - R_1v_o = 0$$

Substituting by V_x

$$v_o(1 + SR_2C_2)(R_1 + R_2 + SR_1R_2C_1) - R_2v_i - R_1v_o = 0$$

$$v_o[(1 + SR_2C_2)(R_1 + R_2 + SR_1R_2C_1) - R_1] = R_2v_i$$

$$\frac{v_o}{v_i} = \frac{R_2}{(1 + SR_2C_2)(R_1 + R_2 + SR_1R_2C_1) - R_1}$$

$$\frac{v_o}{v_i} = \frac{1}{S^2R_1R_2C_1C_2 + S(R_1C_1 + R_1C_2 + R_2C_2) + 1}$$

We choose R=10k Ω and C=100 μF to produce a circuit with time constant τ=RC=1 second.

$$\frac{v_o}{v_i} = \frac{1}{S^2 + 3S + 1}$$

The discrete transfer function for the above filter is:

$$PTF = \frac{4.9503\text{e}-05\text{z} + 4.9011\text{e}-05}{z^2 - 1.9703\text{z} + 0.9704}$$

The aim of this paper is shows the dynamics response of PID controller and fuzzy logic controller to control the transient response and with different fuzzy rules.

The PID controller which used to study the transient response of the second-order filter is shown in figure 2.

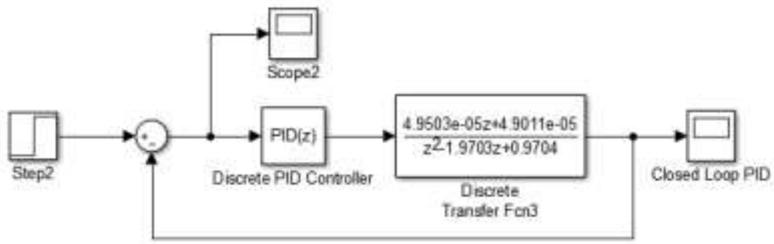

Fig -2: Simulink Model for Discrete PID Controller

The simulation results of the PID controller is shown in figure 3.

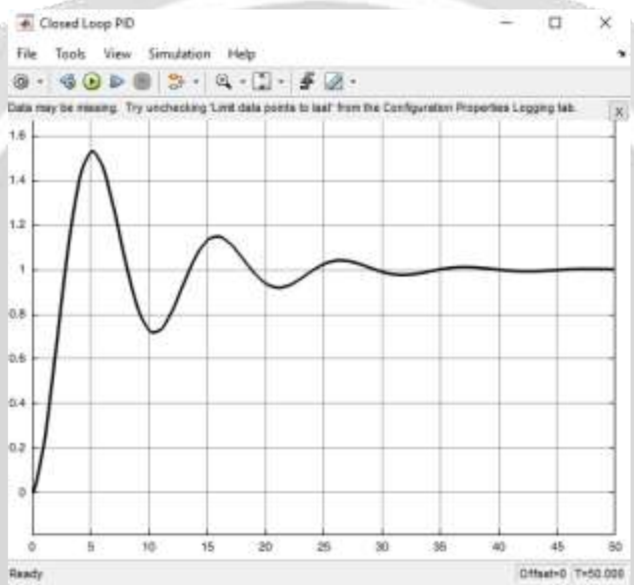

Fig -3: Discrete PID Controller Response

The transient response is shown in figure 3. It is clear from the response that the system success to reach the unit step value so the system can follow the reference input with zero steady state error. Finally, system reaches its steady state response when time reaches to 45 sec.

2. PROPOSED FUZZY LOGIC CONTROLLER

Fuzzy logic was put forward earliest in 1965 by L.A. Zadeh. One of the primary applications of fuzzy logic was subway system in Sendai city of Japan. The applied result showed that fuzzy logic control was superior to traditional control. But finding out the correct rule set and determining the essence and range of fuzzy variables is time consuming work. Such as in subway system of Sendai, to obtain correct input sets, the engineers spent several months.

The general architecture of a fuzzy system is shown in figure 4. It consists of five components: Fuzzifier converts crisp inputs into fuzzified data, Rule base contains if-then rules; which are required by the Fuzzy Inference System (FIS), Database defines membership functions of the fuzzy sets, FIS generates aggregated fuzzified data; based on fuzzy inference method, and Defuzzifier converts the aggregated fuzzified data into a scalar value (score). The final decision obtained by using the score value [7].

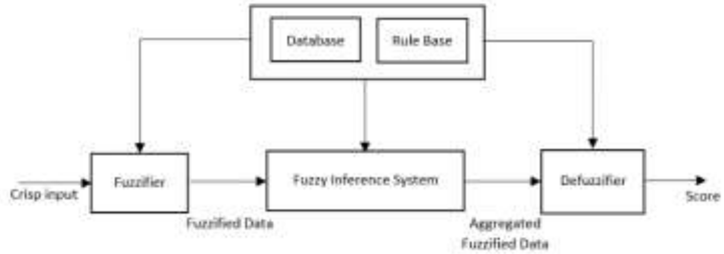

Fig -4: Architecture of a Fuzzy Logic System [7]

For fuzzy logic controller, there are two inputs error (E) and change in error (dE) to fuzzy controller and a single output (U) as shown in figure 5.

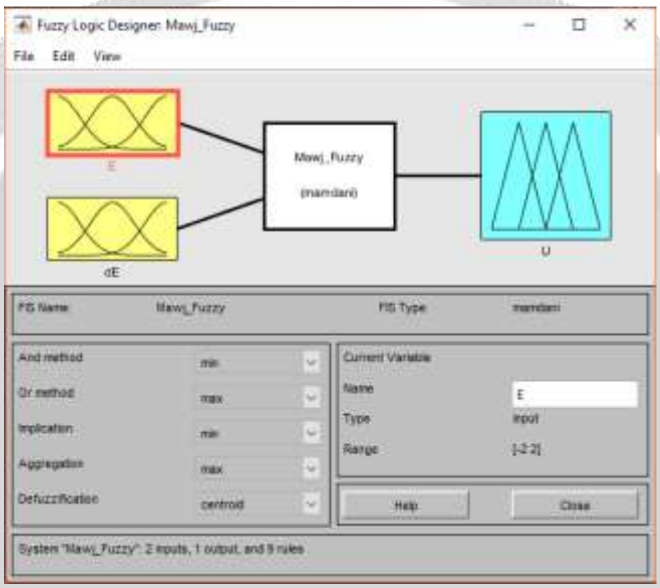

Fig -5: Fuzzy Logic System

2.1 Fuzzy Logic 9-Rules

The nine rules are used for the computation of output U. The universe of discourse each variable E, dE is [-2, 2] while the output U is [-1, 1]. For input variables there are three Membership Functions named as Negative (N), Zero (Z) and Positive (P) as shown in figure 6. For output variable there are three membership functions named as Negative (N), Zero (Z) and Positive (P) as shown in figure 7.

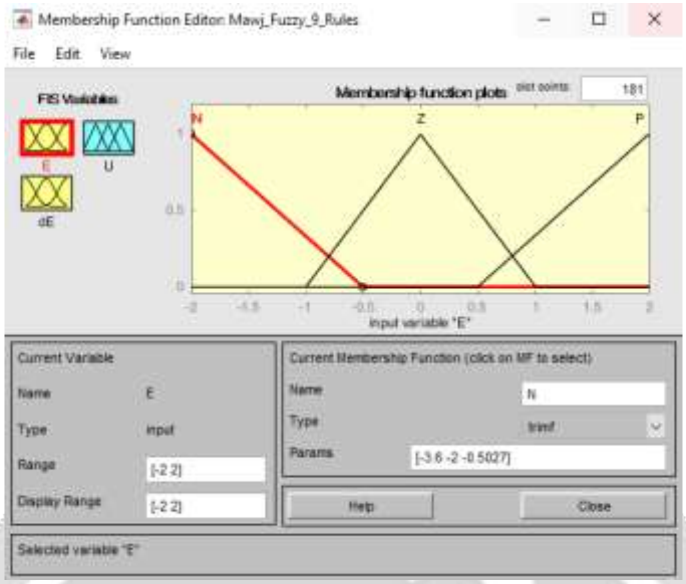

Fig -6: Input Membership Function

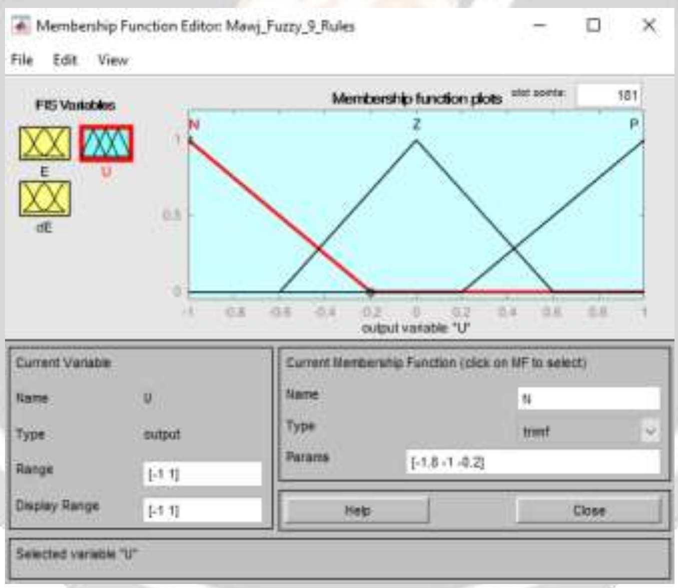

Fig -7: Output Membership Function

The 9-rules which proposed to implement the second-order filter problem are listed in Table 1.

Table -1: Proposed 9-Rules of Fuzzy Logic Controller

	N	***Z***	***P***
N	*N*	*N*	*Z*
Z	*N*	*Z*	*P*
P	*Z*	*P*	*P*

2.2 Fuzzy Logic 25-Rules

The 25 rules are used for the computation of output U. The universe of discourse each variable E, dE and U is [-5, 5]. For input variables there are five Membership Functions named as Negative Small (N_A), Negative Large (N_B), Zero (Z), Positive Small (P_A), and Positive Large (P_B) as shown in figure 8. For output variable there are five membership functions named as Negative Small (N_A), Negative Large (N_B), Zero (Z), Positive Small (P_A), and Positive Large (P_B) as shown in figure 9.

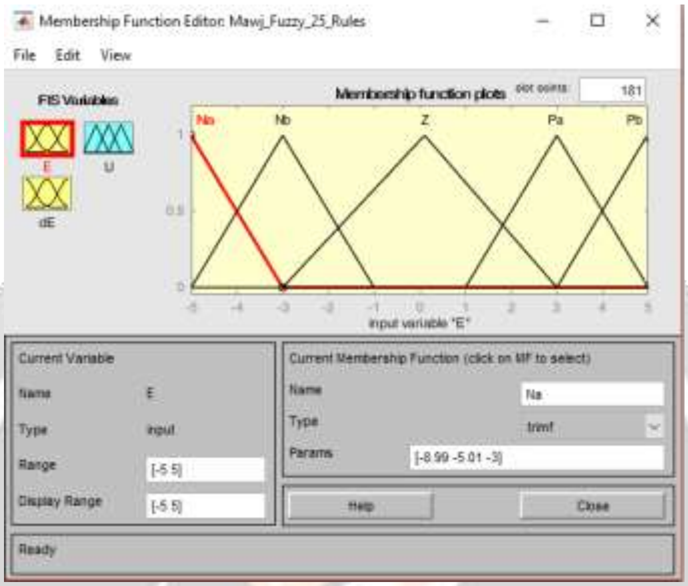

Fig -8: Output Membership Function

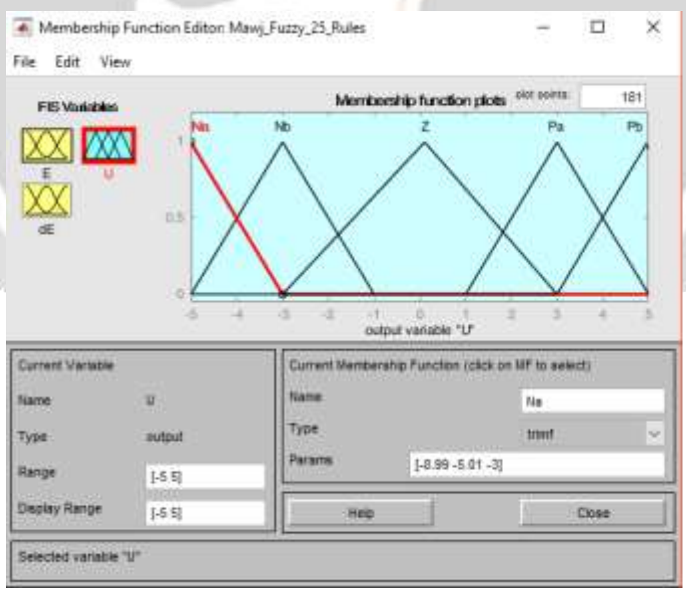

Fig -9: Input Membership Function

The 25-rules which proposed to implement the second-order filter problem are listed in Table 2.

Table -2: Proposed 25-Rules of Fuzzy Logic Controller

	N_A	N_B	Z	P_A	P_B
N_A	N_A	N_A	N_A	N_B	Z
N_B	N_A	N_A	N_B	Z	P_A
Z	N_A	N_B	Z	P_A	P_B
P_A	N_B	Z	P_A	P_B	P_B
P_B	Z	P_A	P_B	P_B	P_B

3. FUZZY LOGIC CONTROLLER SIMULATION RESULTS

3.1 Fuzzy Logic 9-Rules

The fuzzy logic controller which used to study the transient response of the second-order filter is shown in figure 10.

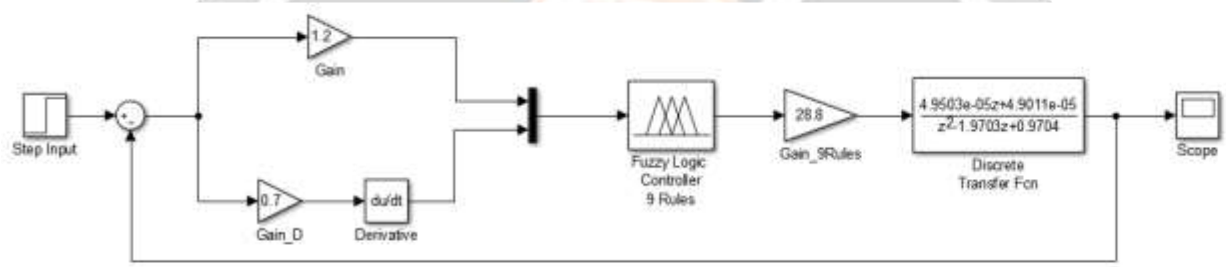

Fig -10: Simulink Model for Discrete Fuzzy Logic Controller (9-Rules)

The simulation results of the Fuzzy Logic Controller (9-Rules) is shown in figure 11.

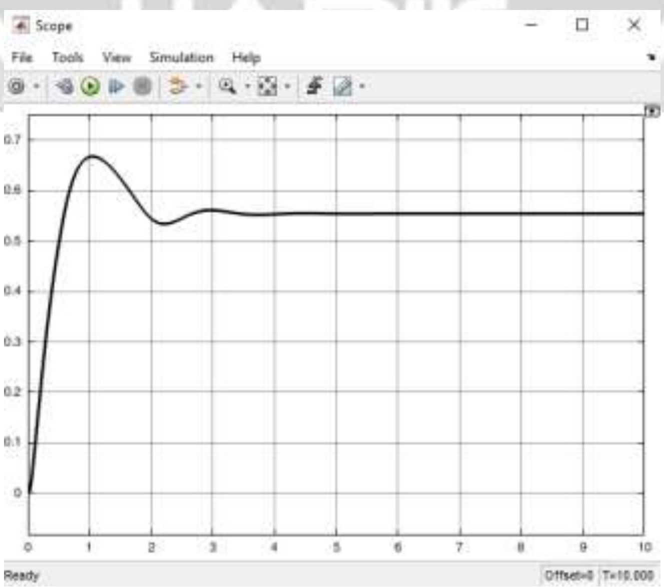

Fig -11: Fuzzy Logic Controller (9-Rules) Response

The transient response is shown in figure 11. It is clear from the response that the system can't reach the unit step value so the system can't follow the reference input. Finally, system reaches its saturation value when time reaches to 4 sec. The response in figure 11 is faster than response of PID in figure 3 but it's not acceptable because the steady state error exist with fuzzy logic model of 9-rules. As a step to optimize the second-order filter response, we will apply another fuzzy logic model with 25-rules as discussed in section 2.2.

3.2 Fuzzy Logic 25-Rules

The fuzzy logic controller which used to study the transient response of the second-order filter is shown in figure 12.

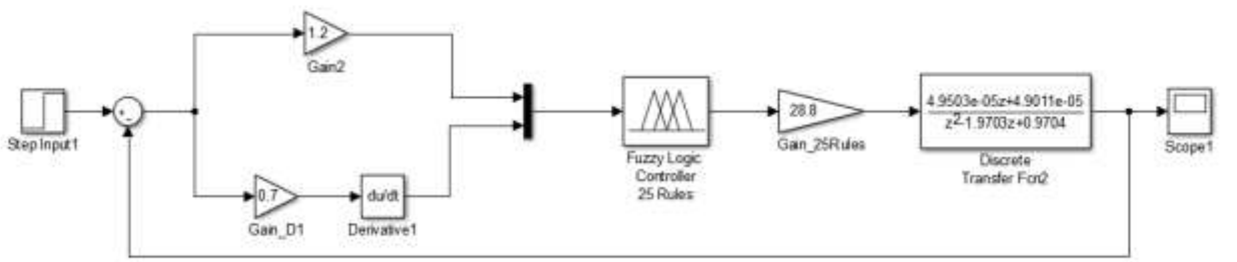

Fig -12: Simulink Model for Discrete Fuzzy Logic Controller (25-Rules)

The simulation results of the Fuzzy Logic Controller (25-Rules) is shown in figure 13.

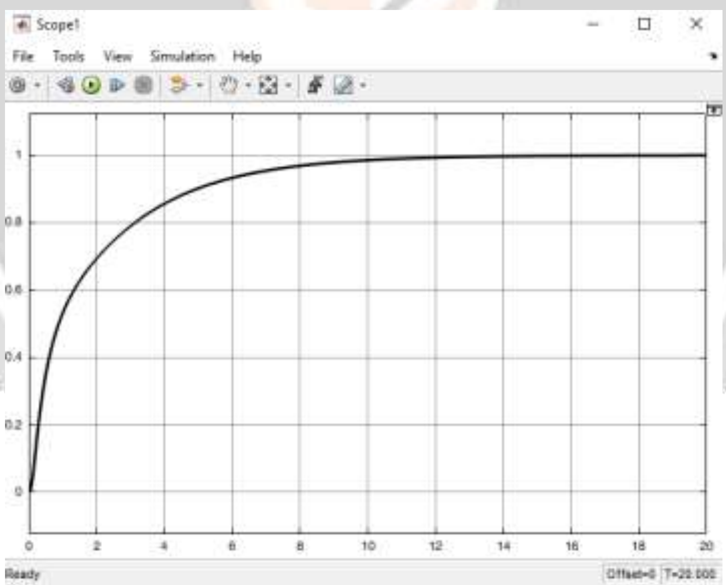

Fig -13: Fuzzy Logic Controller (25-Rules) Response

The fuzzy logic model of 25-rules transient response is shown in figure 13. It is clear from the response that the system success to reach the unit step value so the system can follow the reference input with zero steady state error. Finally, system reaches its steady state value when time reaches to 10 sec. The response in figure 13 is slower than response of fuzzy logic model of 9-rules in figure 11 but it's the optimum response because the steady state error eliminated with fuzzy logic model of 25-rules.

4. CONCLUSIONS

We proposed a fuzzy logic controller based scheme for PD-type which is tuned online by adjusting its output gain parameters depending on the process trend. The most important feature of the proposed scheme is that it is process independent. The proposed technique has been tested on a second-order system with different number of rules (9-rules and 25-rules). In case of 25-rules, the proposed technique provided remarkably improved performance compared to 9-rules model and PID. The transient response output from the model of 25-rules is improved of a faster settling time (10 seconds) compared with PID model which has a settling time of (45 seconds) and the steady state error is eliminated. There is a still scope for future improvements. In the future, making a modifications on fuzzy model of 9-rules to makes the transient response output reach the reference input with zero steady state error, a comparative study can be making by applying the fuzzy model of 25-rules for a different types of filters. Also the combination of Fuzzy and Neural Network and Adaptive-Neuro Fuzzy Inference System (ANFIS) techniques will use for better results. Neuro-fuzzy PID controller can be designed by the implementation of neural network to fuzzy PID controller. There are several areas of investigation which needs to be explored. For systems with high order dominant dynamics, PID control is generally not adequate and accordingly upgrading the existing PID design that handle dominant high frequencies needs to be further explored. This will lead to higher order and more complex controllers. The simple structure of PID controllers limits their performance and systems with large delays or with complex dynamics are hard to control with these controllers.

5. REFERENCES

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