Antenna Azimuth Position Control with Fuzzy Logic and Self-Tuning Fuzzy Logic Controllers

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Abstract

In this study, an antenna azimuth position control system is used to be controlled by a classical proportional-integral controller (PI), fuzzy logic controller (FLC) and a self-tuning fuzzy logic controller (STFLC). The proposed self-tuning fuzzy logic controller is designed via Matlab/SIMULINK environment in order to tune the scaling factors G_1 and G_2, the fuzzy gains of the controller inputs error and its change, on-line. Simulation results show that the performance of proposed controller is better than the other controllers in terms of the settling time and overshoot.

1. Introduction

Since the development of many satellites and radar systems, importance of these control systems with acceptable accurate and impeccable position has increased in industrial and communication areas. Antenna azimuth position control system is currently available together with some control methods, some of which are fuzzy logic and PID controllers. Besides these methods, in this study, a self-tuning fuzzy logic controller designed in Matlab/Simulink environment is used for controlling the position of an antenna in a spherical coordinate system called azimuth.

The position command of the antenna is entered manually with the help of a potentiometer to adjust the angle of it. A second potentiometer is used to get feedback knowledge of the system.

Orientation of the antenna to the desired angle, an armature controlled dc servo motor is used. Motor is connected to the antenna with the help of a gear system. Schematic representation of the system is shown in Fig. 1. [1,2].

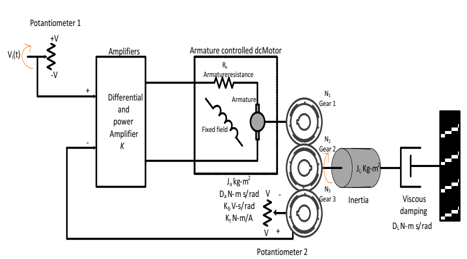

Fig.1 . Schematic representation of the antenna azimuth position control system.

Also, functional block diagram of the antenna azimuth position control system is given in Fig. 2. [1].

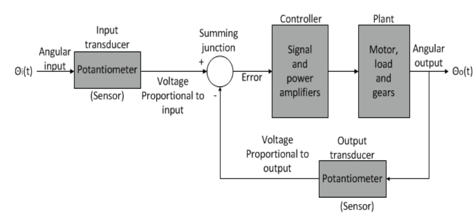

Fig.2. Functional block diagram of the antenna azimuth position control system.

2. System Model

As expressed in previous section, an antenna azimuth position control system consists of two potentiometers which first one is used as input and the second one is used as a feedback, a preamplifier, a power amplifier, an armature controlled dc motor and a load which is antenna. Detailed block diagram of the antenna azimuth position control system is shown in Fig. 3 [1].

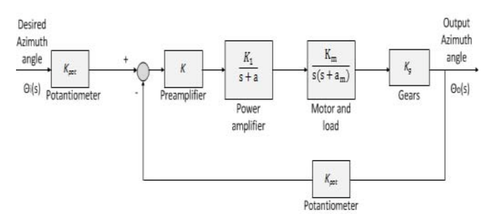

Fig.3. Detailed block diagram of the antenna azimuth position control system.

The transfer functions of motor and load block shown in (1).

$$\frac{\Phi_m(s)}{E_a(s)} = \frac{K_m}{s(s+a_m)} \tag{1}$$

The dampening and inertial components of the antenna are adjusted with the help of gear ratios as seen in (2).

$$K_g = \frac{N_1}{N_2} \qquad (2)$$

In (2), N1 and N2 are the gear teethes shown in Fig 1. Calculations of dampening and inertial components are given in (3) and (4).

$$J = J_a + J_L (K_g)^2 \qquad (3)$$

$$D_m = D_a + D_L (K_g)^2 \qquad (4)$$

In the above equations, J_a is the motor inertial constant (kg-m2), JL is the load inertial constant (kg-m2), Da is the motor dampening constant (N-m s/rad) and DL is the load dampening constant (N-m s/rad).The pole and zero of the motor and load block diagram is calculated as seen in (5) and (6).

$$a_m = \frac{D_m R_a + K_b K_t}{J R_a} \qquad (5)$$

$$K_m = \frac{K_t}{J R_a} \qquad (6)$$

In these equations, Ra is the motor resistance (ohm), Kb and Kt are back EMF constant (V-s/rad) and motor torque constant (N-m/A) respectively. Block diagram parameters of preamplifier, power amplifier, gears and other parameters are given in appendix [1].

In Appendix, Table I, "K" represents the preamplifier block and it is a gain value. The preamplifier gain "K" is calculated by using Routh-Hurwitz criterion. According to this criterion "K" is selected as 100 in the limited range.

3. Design of the Proposed Controller

In order to increase controller performance by tuning the range values of fuzzy subsets of error and its change used in direct fuzzy controller, STFLC is developed. The symbols of on-line changing fuzzy gains are G1 and G2 respectively for error (e) and change of error (Δe). For adjusting to optimal the gain parameters G1 and G2, two fuzzy logic controllers are used. The inputs of gain-adjusting FLCs are system output and error signal. Structure of self-tuning FLC is shown in Fig. 4.[3-4]

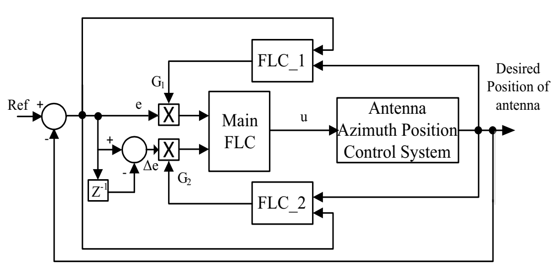

Fig. 4. Structure of the self-tuning fuzzy logic controller.

A fuzzy logic controller consists of three sections, which are fuzzification, rule base and defuzzification sections as shown in Fig. 5. [5-17].

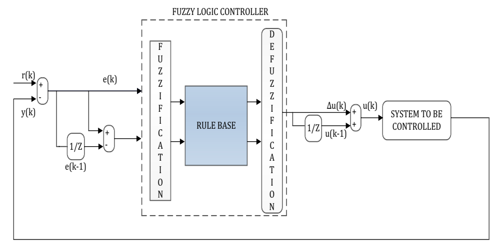

Fig.5. Basic structure of fuzzy logic controller.

As seen in Fig. 5, the input values of the fuzzy logic controller are error (e) and its change (Δe). These two values are as defined in (7) and (8).

$$e(k) = r(k) - y(k) \qquad (7)$$

$$\Delta e(k) = e(k) - e(k-1) \qquad (8)$$

Respectively, r(k), y(k) and k are expressed as reference to input, actual output and iteration counter. Two inputs of the fuzzy logic controller are crisp values.[6-14]

In fuzzification process, these crisp values are converted into fuzzy membership values. To get fuzzy membership values, error and its change are divided into three fuzzy subsets. These are negative (N), zero (Z) and positive (P). Triangular membership functions are used to represent fuzzy subsets as shown in Fig. 6.

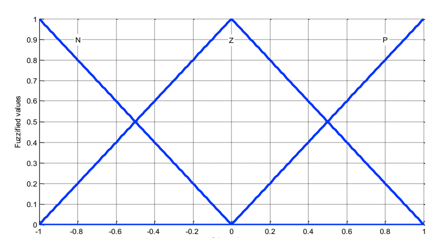

Fig.6. Triangular membership functions of each fuzzy subset.

These fuzzy membership values are used in rule table to activate the related rules [3-7]. The mathematical formulation of triangular membership function is shown in (9).

$$A_\Delta = \max\left(\min\left(\frac{x - x_1}{x_T - x_1}, \frac{x_2 - x}{x_2 - x_T}\right), 0\right) \qquad (9)$$

In this study, performances of different type membership functions such as trapezoid, bell, Gaussian, Cauchy, sigmoid or sinusoid are compared with each other in order to obtain the best system response. The mathematical representation of some of these membership functions are shown below.

$$A_G = e^{-\frac{1}{2}\left(\frac{x-x_T}{W}\right)^2} \quad (10)$$

$$A_C = \frac{1}{1+\left(\frac{x-x_T}{d}\right)^{2m}} \quad (11)$$

$$A_B = \frac{1}{1+\left|\frac{x-x_T}{d}\right|^{2m}} \quad (12)$$

A rule based consists of data about the related system. In this project, a nine, twenty-five and forty-nine rules fuzzy logic controller are designed and tested to get the best system response with proposed controller. One of these rules utilized in making decisions are as defined in Table I.

Table 1. 3x3 Rules for the fuzzy logic controller.

		Change of error (Δe)		
		P	Z	N
Error (e)	P	P	P	Z
	Z	P	Z	N
	N	Z	N	N

In order to get the control signal in defuzzification section, center of area method is used [8-13]. Maximum membership degrees of the corresponding fuzzy subset are multiplied by fuzzy membership values. Then, sum of these products is divided by fuzzy membership values and change of control signal is obtained. The general expression of the center of area method is given in (13).

$$\Delta U(k) = \frac{\sum_{i=1}^{n} \mu_i(\Delta u_i)\cdot \Delta u_i}{\sum_{i=1}^{n} \mu_i(\Delta u_i)} \quad \text{for i=1,2,..,n} \quad (13)$$

A generalized overlooked view of the fuzzy logic controller is shown in Fig. 7. In this figure, subsets of inputs are error; change of error and change of control signal are limited between positive one and negative one. But, three gain coefficients are added to fuzzy logic controller to change the limits of different type of fuzzy logic membership functions. Depending on the system, these coefficients used to adjust the limit membership functions may vary [3-15].

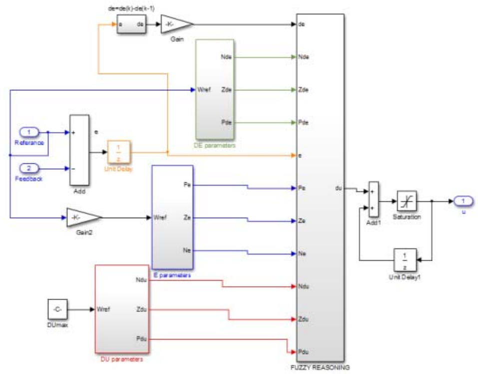

Fig.7. Generalized overlooked view of the fuzzy logic controller.

The manuscripts must be prepared in a two-column format on A4 size paper. The margins on the first page must be as follows: top = 3 cm, bottom = 3.7 cm, left = 2 cm, right = 2 cm. All margins on the second and subsequent pages: top = 2.5 cm, bottom = 3.7 cm, left = 2 cm, right = 2 cm. The text of the paper must be written in two columns with a space of 0.5 cm between them (Fig. 1). The width of each column must be 8.25 cm. On the last page of the paper, the lengths of the columns must be adjusted so that they are equal. Do not add page numbers.

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4. Application and Results

In order to obtain the best system response with fuzzy logic controller, firstly different type fuzzy membership functions are performed. System responses with triangle, trapezoid, Cauchy, Gaussian and bell type fuzzy membership functions are shown in Fig. 8. 10 turns is applied to the system as an input.

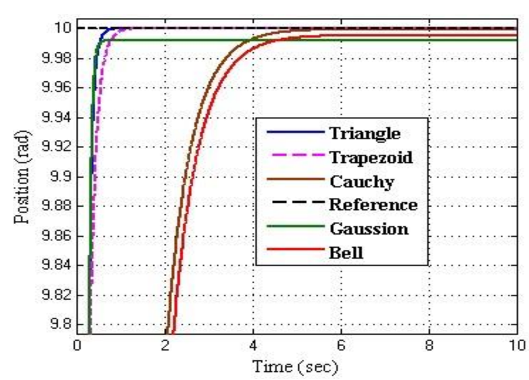

Fig.8. System responses with different type fuzzy membership functions.

As seen in Fig. 8, the fastest system response without steady-state error is obtained by using triangular fuzzy membership function. Since triangular fuzzy membership function has sharper and more sensitive transitions between its subsets compared to other membership functions, it is expected result to get the best answer with triangular type fuzzy membership function.

After determining the membership function type, 3x3, 5x5 and 7x7 fuzzy rule tables are tested by using triangular membership function. System responses with different number of rules of fuzzy logic controller are shown in Fig. 9.

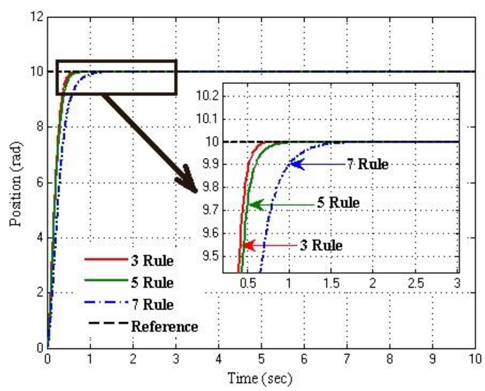

Fig.9. System responses with various fuzzy rule tables.

As seen in Fig. 9, no overshoot is seen with different number of fuzzy rule tables. Due to reduced number of calculation, the fastest system response is obtained by using 3x3 fuzzy rule table.

After obtaining the best antenna azimuth position control response with triangular membership function and 3x3 fuzzy rule table, the performance of fuzzy logic controller is compared with a classical PID controller. Parameters of the PID controller are chosen as Kp=6, K_i=0.1 and K_d=1.5 respectively.

System block diagram model with PID controller and FLC are shown in Fig. 10.

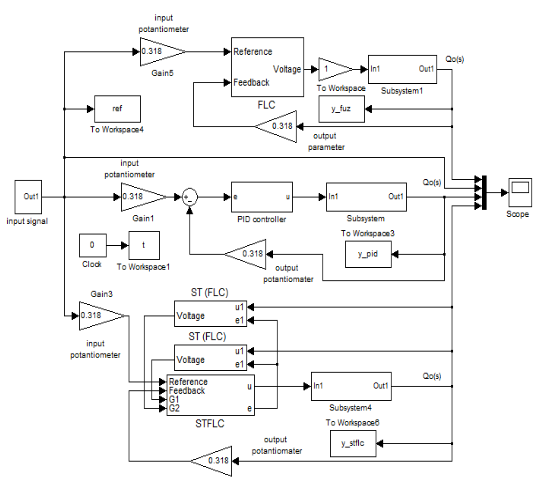

Fig.10. Matlab/Simulink model representation of the system with FLC, STFLC and PID controller.

Antenna azimuth position control system responses with FLC and PID controller are shown in Fig. 11. As an input to the system 10 turns are applied via potentiometer.

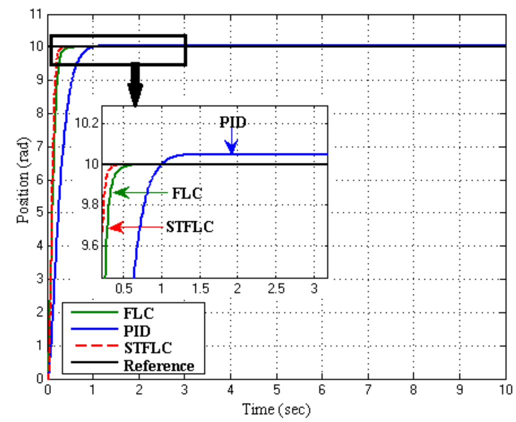

Fig.11. System responses of FLC, STFLC and PID controller with fixed reference signal

As seen in Fig. 11, by using STFLC, a better system response is obtained. Performances of these two controllers are also compared with variable input values that are changed from 0 turn to 180 turns and 180 turns to 0 turn by increasing and decreasing 10 turns to potentiometer. Comparison of the performances with variable input turns are shown in Fig. 12.

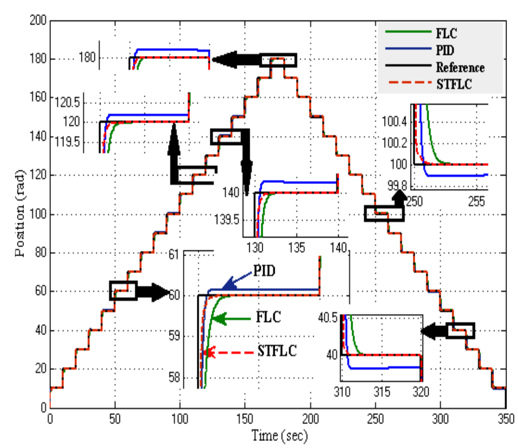

Fig.12. System response of FLC, STFLC and PID controller with variable reference signal.

5. Conclusion

In this study, an antenna azimuth position system is controlled with FLC, STFLC and PID controllers designed in Matlab/Simulink environment. In order to obtain the best system response, various types of fuzzy membership functions and various numbers of fuzzy rules are examined. To see the performances of controllers, they are compared with each other. As a result, it is observed that STFLC gives better results than FLC and PID controller.

6. Appendix

Table II. Block diagram and motor parameters of the antenna azimuth position control system.

Parameters	Configurations
K_{pot}	0.318
K	100
K_1	100
a	100
K_g	0.1
N_1	25
N_2	250
J_a	0.02
J_L	1
J	0.03
D_a	0.01
D_L	1
D_m	0.02
K_b	0.5
K_t	0.5
R_a	8
a_m	1.71
K_m	2.083

7. Referances

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