A Novel Low Complexity Fast Response Time Fuzzy PID Controller for Antenna Adjusting Using Two Direct Current Motors

Vahid Rahmati[1*] and Amir Ghorbani[2]

[1]Ayandeh Samin Electronics and ICDST, Tehran, Iran; vahid.rahmati@icdst.org
[2]International Center for Developing Science and Technology (ICDST), Tehran, Iran; a.ghorbani@icdst.org

Abstract

Objectives: A novel PID Controller (PIDC) for the purpose of adjusting an antenna in 360 degrees range by direct current (DC) motors using Fuzzy method is designed and simulated. **Methods:** For this, first, an accurate model for DC motor in simulations is developed- that can be replaced by any other dynamic, for e.g., a high power low speed motor, however, the response in this case will be different. The controller mentioned uses the Mamdani type in two working modes with 3 and 4 inputs setting the full control of two independent DC Motors (DCMs). **Findings:** Clearly, the modes with 3 and 4 inputs occupy 27 and 81 commands respectively to have smooth overshoot and under shoot responses. Some of the parameters are acquired experimentally that can be modified for various applications, although these values are also remarked for the possible re-simulation by the readers. **Application:** However the PIDCs have many applications in industry, the main application of our PIDC is intended for radar systems where the antenna needs to quickly rotate in order to accurately receive the reflections from certain paths.

Keywords: Antenna Adjusting, DC Motor Controlling, Fuzzy Controller, Low Complexity Controlling, PID Controller

1. Introduction

Using the PIDCs has a long history behind[1], but using an appropriate Fuzzy replacement can be a practical topic as many new applications of the Fuzzy logic emerge every day. The main benefit of implementation of Fuzzy systems as controllers is because of simplicity of use as only little information about the system is sufficient. Total cost is also another reason why many move towards Fuzzy, adaptive Fuzzy (not ineffectual to call pseudo-Fuzzy), and Artificial Neural Networks (ANNs) based designs[2–6].

Regardless of the ANNs and Fuzzy logic, some algebraic methods exist that may also be comparable to these systems such as the one developed in part IV in[7] where a detailed review of system approximations is also described. Besides Fuzzy systems' applications in engineering, the Information Technology (IT), specially the field of Big Data (BD)[8], also uses smart Fuzzy methods in dealing with threats including cyber attacks[9]. Recently the Fuzzy logic is also employed for Elliptic curve cryptography showing the wide ranges of emerging applications[10]. Authors in[11] surveyed a wide increasing range of applications of Evolutionary Computation (EC) methods- as a rival to Fuzzy systems- having many practical aspects for control engineering.

Other resources also have done controlling on antenna for perfect positioning of them[12]. In this article, a Mamdani controller[13] in two modes is employed to control two DCMs using parameters: *e*, *ep*, and *ei* which denote error, its derivative, and integral respectively; and for the mode with 4 inputs we have *e*, *ee*, *ep*, and *ei* defined as before except for ee that's a supplementary parameter chosen for facility of the procedures[14].

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*Author for correspondence

2. Modeling of a Selected DCM and Other Control Parameters

In this part, first a DCM dynamic is presented in order to be used in next circuits. Of course, DCMs can be modeled differently as each one exhibits various properties such as torque, power consumption, voltage, current, response time and more. In this paper, we've presented the DCM used clearly to validate the simulation results based on this model. It will be mentioned that the researchers may change such model and re-run the simulations for comparison of graphs.

2.1 DCM Dynamics

The DCM exhibits its own response as different motors are ranged for different torques, powers, and some other attributions; so the same exact controller may not be used for all models of motors, yet it's possible to do so if the design parameters are re-set well[15]. To clarify what type of DCM is PID controlled in this article, the equivalent circuit for its dynamics is provided in Figure 1. Please notice that common DCMs are greatly efficient, and their features make them proper for usage as servomotors. Nevertheless, the main disadvantage is that the DCMs need a commutator and two brushes which are subject to wear and require maintenance. This has been resolved by implementing the tasks of these two components by solid-state switches resulting in maintenance-free DCMs[16].

The respected readers can replace this model by any other replica that is expected in their design-necessitating changing some control parameters presented in next part, but before that, the differences between Mamdani and Sugeno inferences are briefly expressed.

2.2 Mamdani Vs. SugenoTypes of Controllers

In this research, Mamdani controllers are chosen with both Fuzzy type in inputs and outputs plus triangular membership functions instead of the familiar Gaussian membership function giving similar outcomes. The reason behind using triangular type instead of Gaussian type is the faster response of the system as the calculation of the second type is more complex[17]. There's no doubt that using Sugeno type make it easier to work with numbers as it's scalar, but in this paper, we use only Mamdani type of controller.

2.3 Control Parameters

Usual parameters[18,19] in a PIDC are error, derivative, and integral of it used in the mode with 3 inputs, and in this case blocks of Simulink including gain controller, differentiator, and integrator employed to update these parameters. Other control parameters are Bm, Jm, Kb, Km, and R that store the initial and current values of the controller settings acquired in an empirical manner- meaning
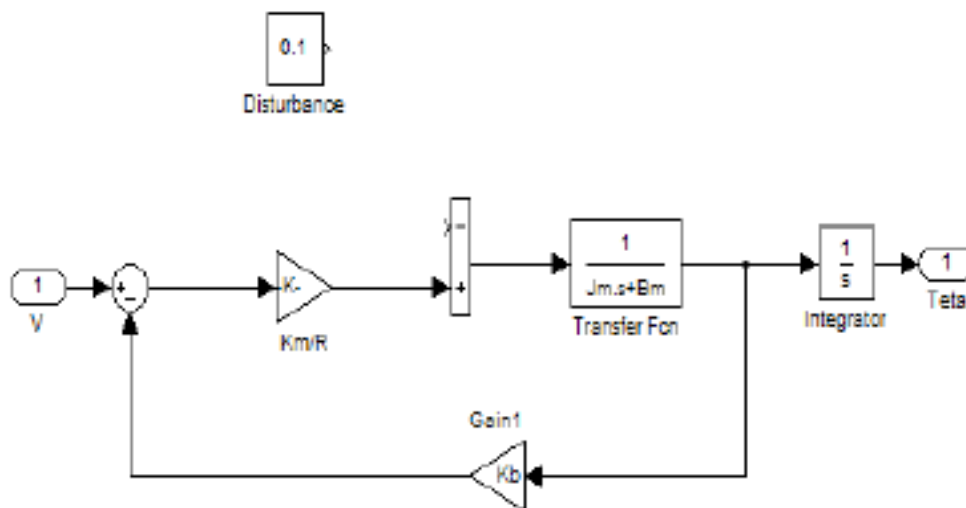

Figure 1. The equivalent circuit of a certain DCM used and PID controlled.

the readers may provide some new and possibly more efficient numbers on the contrary. Little modification of these values doesn't change the nature of the controller (as will be seen in the steady state of the output response), but it leads to lower/higher magnitudes of overshoot/undershoot as the transient state of any response is affected by the initial values. These values are chosen between 10^{-4} and 0.02[20–23]. It's also useful to assert that in PID control project, an Optimization Algorithm (OA) is usually used to search for the ideal controller parameters bringing about the lowest deviation from tracking point and therefore fastest response. The OA is based on some criteria which are defined by an Objective (or cost) Function (OF). For this to work, various OFs have been suggested already by researchers to accomplish better response of the system[24,25].

3. Design of the Circuit for Controlling DCMs

This controller primary was intended for controlling of two DCMs connected to two (or one) antennas in horizontal and vertical axes, therefore, there are some insignificant variations in the design discussed in next parts. Figure 2 shows the details of the design in the simulator environment[26,27].

Indeed, the integrator is in the output of the Fuzzy controller, and the angle (θ) is compared with a reference value and recursively re-input with gain of 0.5, then first order and second order derivatives of it are also injected to the Fuzzy logic controller. Therefore, the first to third inputs respectively play the roles of the integral of error, the error itself, and the derivative of it[28,29].

As the gravity affects the vertical axis non-uniformly compared with the horizontal axis, the second controller circuit uses Fuzzy logic controller with 4 inputs making the system more accurate by reducing the possible vertical tensions during rotations. However, the number of rules then increases to 81 (3^4) with smooth enough control step response. Three differentiators are used in the circuit shown in Figure 3, moreover the error integral coefficients are 1, −0.1 and for the diffrentiator the value 1 is chosen. These values have been set up for the best (fastest) response, however we cannot conclude that the dynamics of the DCM is not effective. For those who have implemented a real world circuit like this, it's clear that
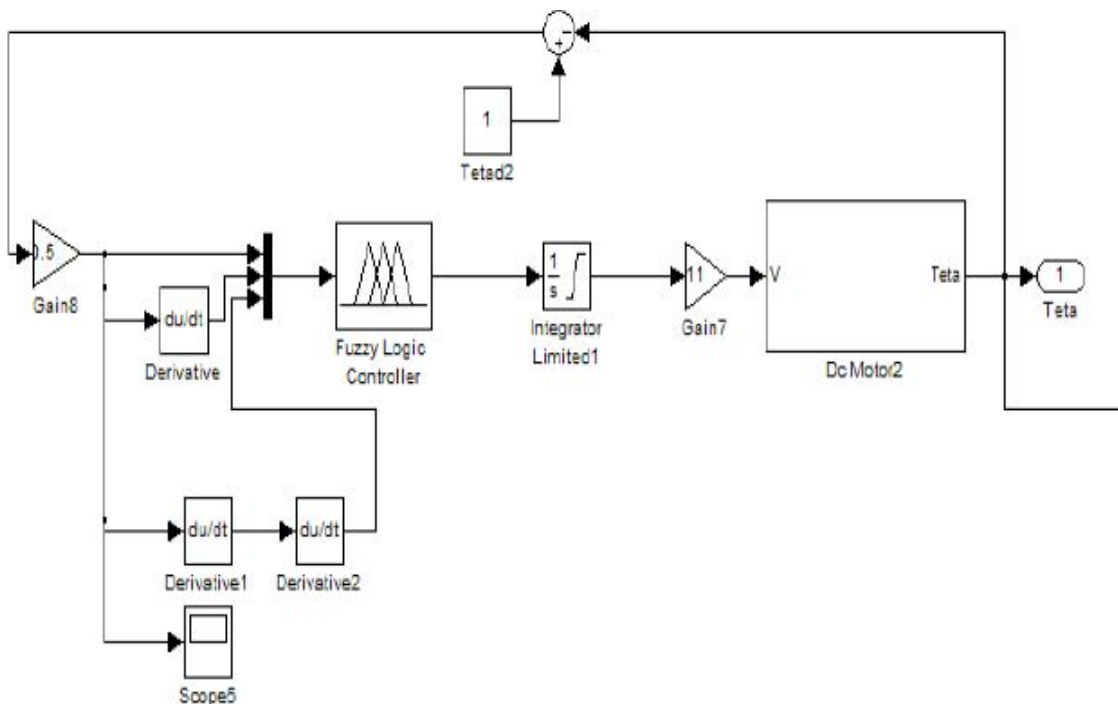

Figure 2. The equivalent circuit of the PIDC for the horizontal axis in line with the DCM A.

the type of DCM can be a game changer- for instance a motor with slow response- making the design very complex and sometimes impossible even with the state of the art mega-fast processors[15,30].

In the simulation, transient response time is ~3 seconds which is not sufficiently fast for certain applications such as radar antenna controlling, therefore other optimizations needed, for e.g., the number of differentiators must be reduced and for better stability tuning, the number of integrators with appropriate gains should be increased. For example in Figure 4 a Fuzzy PD (FPD) controller is introduced[31]:
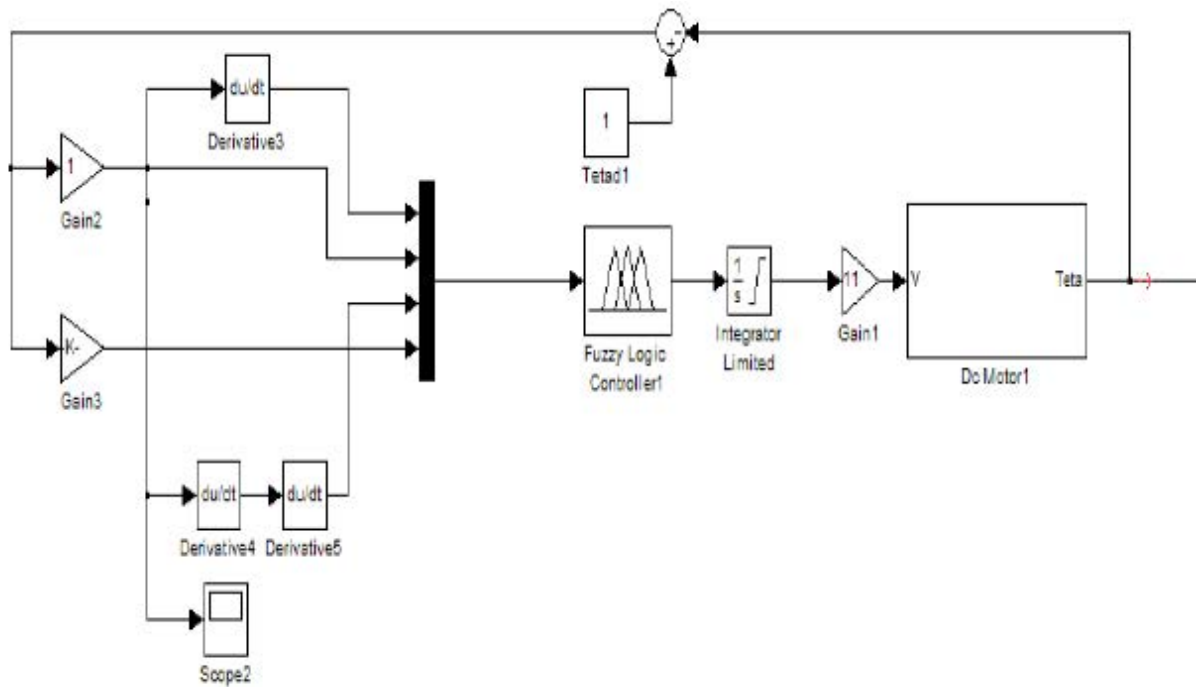
Figure 3. The equivalent circuit of the PIDC for the vertical axis in line with the DCM B.
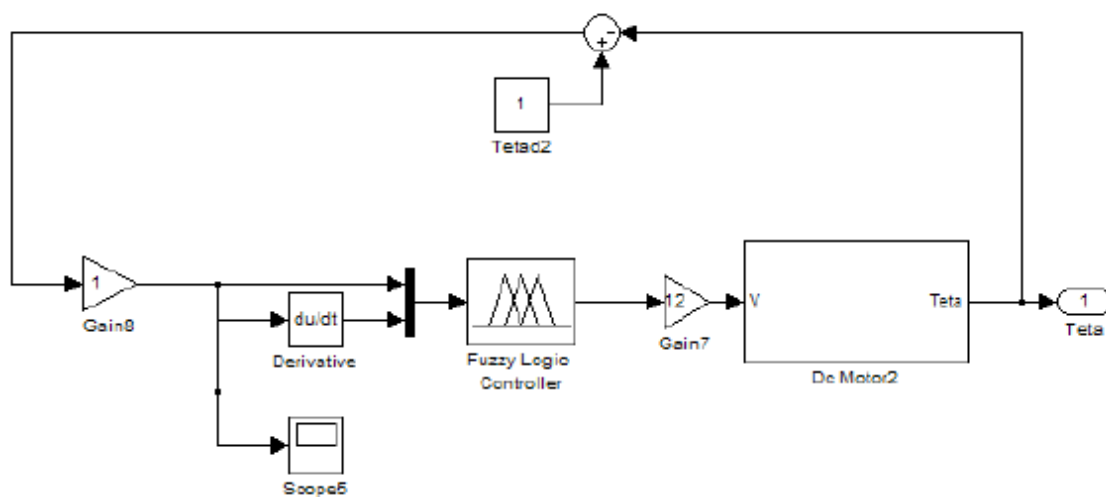
Figure 4. The equivalent circuit of the PD controller for a DCM by reducing integral coefficient.

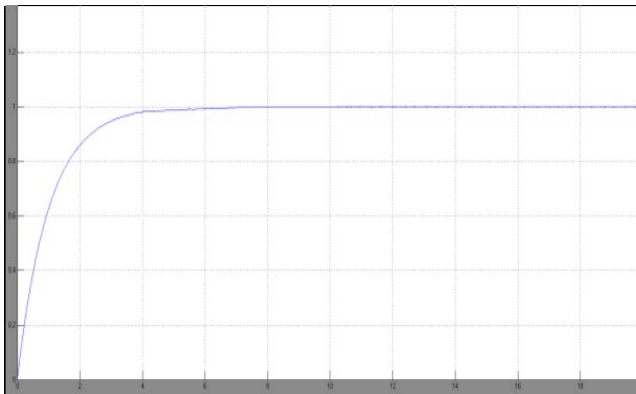The response of this controller is shown in Figure 5.

Figure 5. The response of the PD controller to the input of Heaviside step signal.

As in Figure 4, the integral coefficient is removed making the circuit easily implementable with its two inputs as shown in Figure 6.
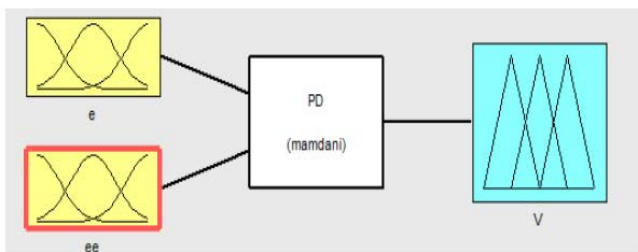

Figure 6. The PD controller with its inputs and output.

It is consisted of only 9 rules in the database. The member ship function of this controller is also presented in Figure 7.
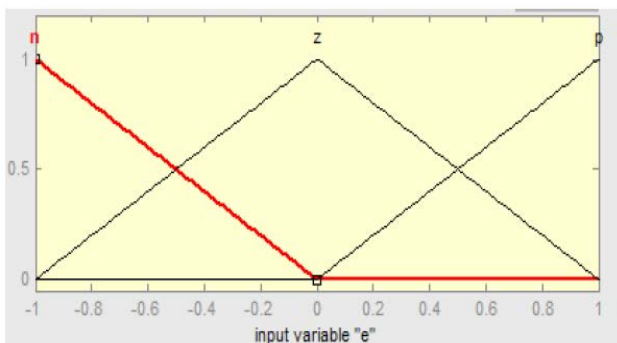

Figure 7. The triangular membership function for the input variable in the PD controller of the Figure 4.

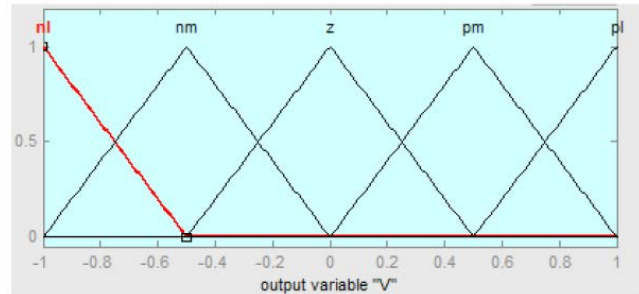The output membership function is also depicted in Figure 8.

Figure 8. The triangular membership function for the output variable in the PD controller of the Figure 4.

As it's shown in Figure 8, all 5 membership functions are in the range of [−1, 1]; particularly, the inputs were named as n, z , and p (or negative, zero, and positive), but for the output the case extended for finer regions resulting in more accurate output with the labels called *nl*, *nm*, *z*, *pm*, and *pl*. We only compared PID and PD here, PI and PID comparison has been also done for motor systems too which is very similar to our design[32].

4. Simulation Results

In this part, firstly, the full circuit is provided in Figure 9, subsequently the rule writing is considered besides graphing the output responses. The full circuit is including both segments of the controller for horizontal and vertical modes. Figure 10 and Figure 11 also demonstrate controller A with its inputs' and output's membership functions.

The second controller also consisted of 4 inputs but it's distinguished from ordinary FPIDCs as it uses 2 gain parameters acquired experimentally. It's also shown in Figure 12.

Figure 13 and Figure 14 also show the simulation results- or the Heaviside step response of the circuit.

The results show how the smooth but still slow responses are achievable at expense of low speed DCM dynamics, however, a new DCM model with faster dynamics can be used for practical purposes. DCM controlling by Fuzzy adjustment gives nearly smooth result the same as Figure 14[33].

5. Conclusion

This article proposed a new FPIDC based on the conventional PIDCs using Mamdani inferences to apply control
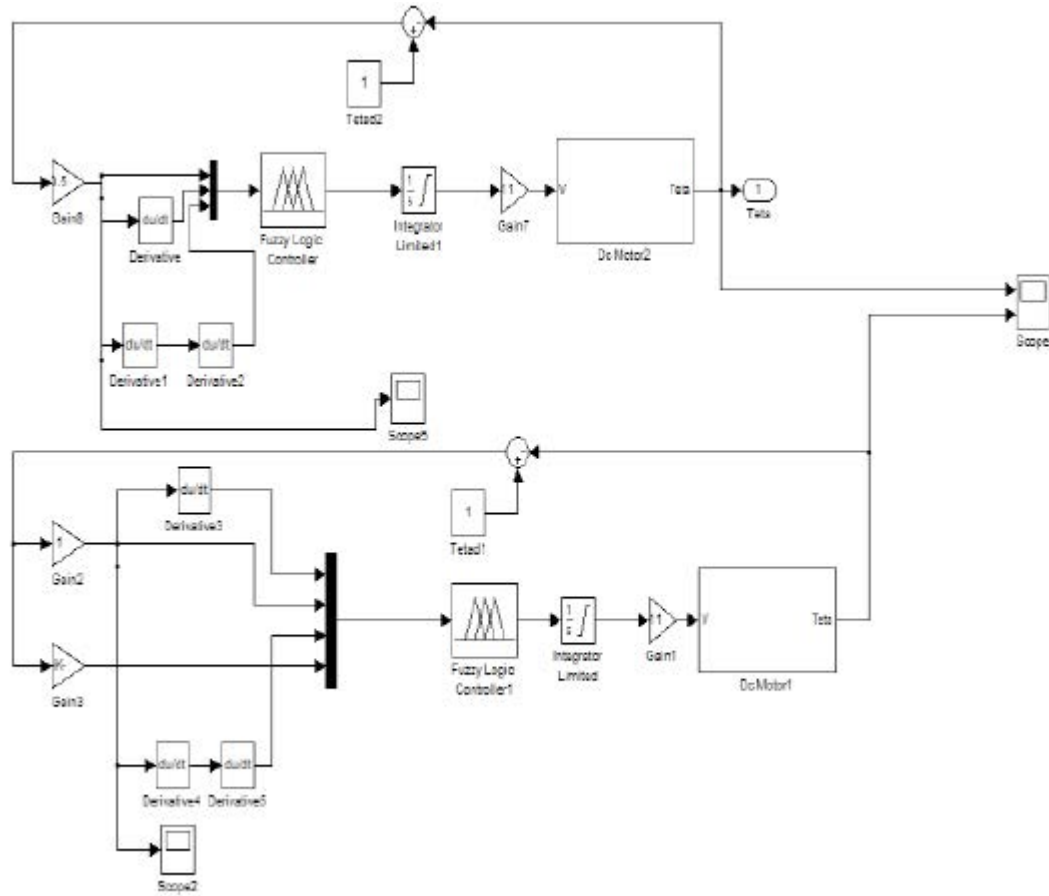
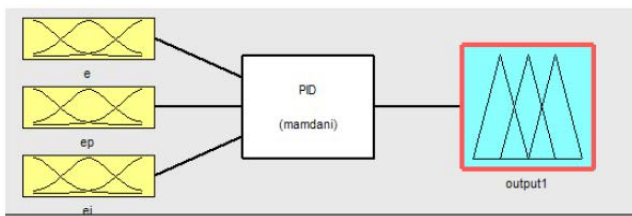**Figure 9.** The full circuit for double DCM Fuzzy PIDCs (FPIDCs).

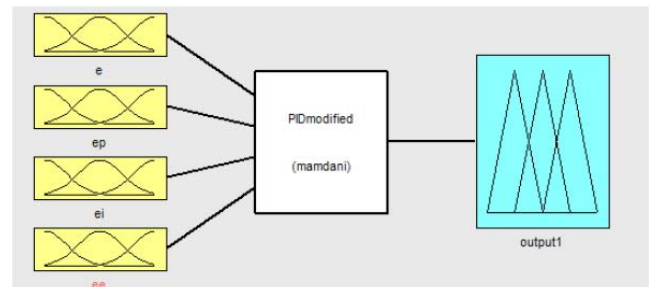**Figure 10.** First controller 3 inputs with single output for the DCM in line with horizontal axis.
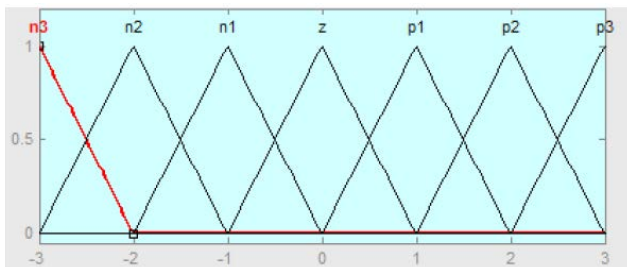

Figure 11. Output's membership functions shown with well-divided regions.

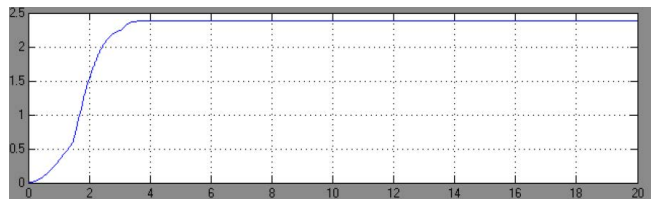**Figure 12.** Output's membership functions of the first controller.

Figure 13. Simulation response of the first (horizontal axis) controller to the Heaviside step function.
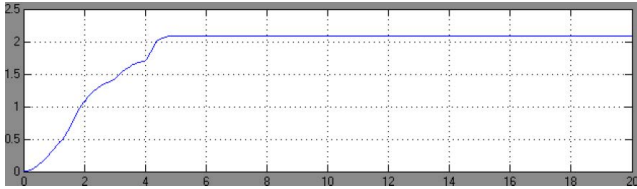
Figure 14. Simulation response of the second (vertical axis) controller to the Heaviside step function.

on two DCMs assigned in line with horizontal and vertical axes to hold and move an antenna. Circuits with design parameters in addition to the simulation environment information provided, and a comparison between FPID and FPD controllers was partially done.

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