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A Hybrid Fuzzy Logic FOPID Position Controller for DC Motor Driving Tracking Systems System

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Abstract

This paper presents a developed application for using Fraction Order PID controller (FOPID) in controlling of DC motors installed incelestron telescope, this is done through controlling the angles of two DC motors driven the telescope. The model of celestron telescope is mathematically represented by highly non linear differential equations, this types of nonlinear model is recommended to be controlled using Artificial Intelligent based controller. In this paper, optimal fuzzy FOPID is implemented instead of conventional PID controllers. Genetic Algorithm, fuzzy logic are used for tuning the FOPID parameters.FOPID controller is based on position error and its rate of change as an input vector, the proposed controller set presents a complete precision in forcing the telescope motors to satisfy the predefined position. The simulation results show the dynamic response of the system and the enhancement achieved in rising time and settling time when using FOPID. The response of FOPID is compared with the conventional PID with the same input position reference.

***Keywords**: Index Terms - PID, FOPID controller, genetic algorithm, fuzzy logic*

1. Introduction

In the last decades the tracking problem of a certain trajectory had involved in many industrial and militaries DC motor driven applications. One of the most attractive tracking systems is the astronomical telescope; such application depends on two DC motors driving system working together to track a predefined position. A set of control techniques is implemented to achieve accurate, simple and robust output model response [1]. The astronomical telescope mathematical model based on equations continues varying like inertia term, a centrifugal and coriolis term and gravity term, this non linear system force the researcher in a way to design a non conventional controller to obtain a wide range operating point in nonlinear differential equations [2]. The nonlinear systems face many problems in designing such a controllers through implementing conventional PID from point of view of high dynamic response and precision. A modification has been implemented on such controllers through using auto tuning and adaptive PID controller [3-4]. Latterly the non-conventional type of PID controllers based on Artificial Intelligent optimization techniques is designed and simulated for the tracking problem purpose. Finally the Fraction Order PID is used to achieve optimum design of controller by taking into account five different design specifications for the closed loop system taking the advantage of fraction order parameter λ and u.The orders of integration and differentiation are respectively λ and u (both positive real numbers, not necessarily integers). If λ=1 and u=1, so the integer order PID controller has three parameters, while the fractional order PID controller has five parameters.

The fractional order PID controller generalizes the integer order PID controller and expands it from point to plane. This expansion adds more flexibility to controller design and real world processes more accurately controlled [6]. In this paper a modification is done through the conventional PID controllers by using FOPID and fuzzy FOPID with genetic algorithm adaptation which considered as a modification for work implemented in [13].

This paper is divided into six sections; section one represent the introduction, section two presents the dynamic model of Celestron telescope, section three presents the designer of FOPID based Genetic Algorithm Controller, section four presents design of fuzzy FOPID

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based Genetic Algorithm Controller , section five is the simulation results and finally section six is the conclusions.

2. Model Description of Celestron Telescope

The Celestron telescope is a fork-mounted Schmidt Cassegrain (Celestron, 1992), as shown in Figure 1. It includes an optical tube assembly, an electric clockdrive with a worm gear drive and a giant 2 star diagonal. In addition, there is a14visual back, a 10 × 40 finder scope, setting circles, two counter weights barassemblies, a lens cap, carrying cases, and permanent magnet dc motor drives in the Right Ascension (RA) and Declination (DEC) axis to move the telescope on bothSides.

The modeling of these types of systems faces some problem from linearity point of view; the dynamic equations depend on three main variables; inertia term, a centrifugal and coriolis term, a frictional term, and a gravity term equal to zero. These equations are plugged by substantial requirements for computation and the theory underlying their solution is incomplete. The dynamic equations of the telescope are given by Equations (1) and (2) [1] and –[14].

$$M(\theta)\ddot{\theta} + C(\theta, \dot{\theta}) + G(\theta) = \tau \quad (1)$$

$$M(\theta)\ddot{\theta} + N(\theta, \dot{\theta}) + \tau d = \tau \quad (2)$$

Where: θ, $\dot{\theta}$, and $\ddot{\theta}$ are the joint angular position, velocity and acceleration vectorsrespectively. τd is a constant disturbance torque, which represents the unknown dynamics, e.g. friction. Also, each angular position contains the following variables:

$\theta = [\theta 1\ \theta 2]T$, $\dot{\theta} = [\dot{\theta 1}\ \dot{\theta 2}]T$, $\ddot{\theta} = [\ddot{\theta 1}\ \ddot{\theta 2}]T$, $N(\theta, \dot{\theta}) = C(\theta, \dot{\theta}) + G(\theta)$.

Where C is a vector of centrifugal and coriolis terms, G is a vector of gravity term. Figure (1) shows the Simulink block diagram for the Celestrontelescope model. The model and parameters of the Celestrontelescope is taken from [14].

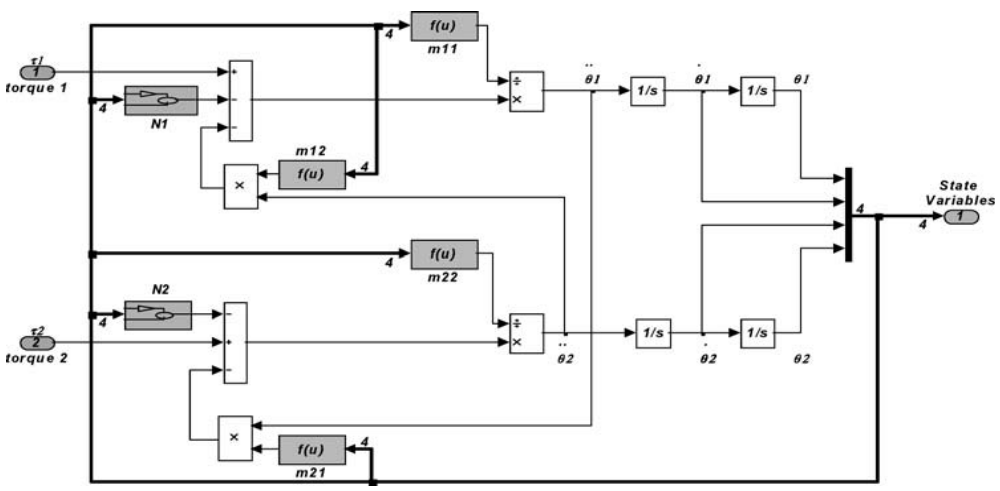

Figure 1. Simulink block diagram for the Celestron Telescope Model

Another problem to be faced is the coupling problem as the inputs for this system is torques $\tau 1$and $\tau 2$controls the outputs $\theta 1$ and $\theta 2$. It is required to decouple this model by introducing a compensator. Consequently a decoupled system can be considered as consisting of a set of independent single-input single-output systems. The compensator with the modelof the telescope results into a linear system, which enables a linear controller such as a PID controller to be used for control. The overall input for nonlinear model of the telescope consists of a compensator plus two PID feedback controllers running in parallel. The controller is consisting of a state feedback compensator and a linear controller processes with state vector [θ1 θ1˙θ2˙ θ2] as shown in Figure 2 [7].

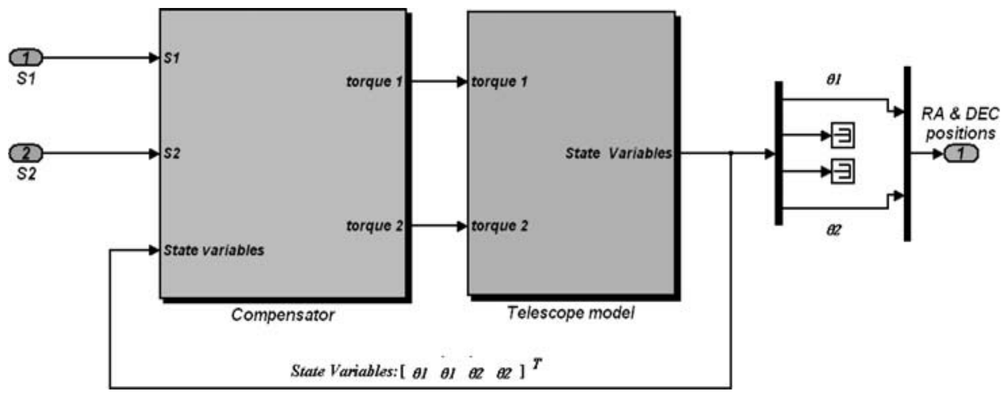

Figure 2. Linear Telescope Model

3. PID based Genetic Algorithm Controller

Artificial Intelligent is considered one of the most recent techniques used in tuning of gain parameters; Genetic Algorithm is implemented in this paper for tuning adaptation for gain parameters of PID controller. GA is probabilistic in nature, not deterministic, which is a direct result of randomization techniques that are used by GA. GA uses the idea of randomness when performing a search, but it must be clearly understood that GA is not simply random search algorithms. They utilize knowledge gained from previous generations combine them with some randomizing features, in order to construct a new generation that will approach the optimal solution. This implies that GA is powerful search techniques that can handle multimodal search.
Many papers have discussed the using of GA in Tuning PID parameters in many applications like in obtaining efficient and fast tuning method based on a modified genetic algorithm (MGA) structure to find the optimal parameters of the proportional-integralderivative (PID) controller in Ref [8] or to be used in positioning control systems in Ref [9] and also in unstable plants as in Ref [10].

This section presents the modified conventional PID model after implementing GA for tuning the gain parameter as shown in Figure 3, where it consists of a conventional PID controller with its parameter optimized by genetic algorithm. The initial population of size N is generated randomly to start the optimization process. The next generation can be obtained through the genetic operators [11]. The implementation of PID controller to the telescope model is presented in Figure 4.

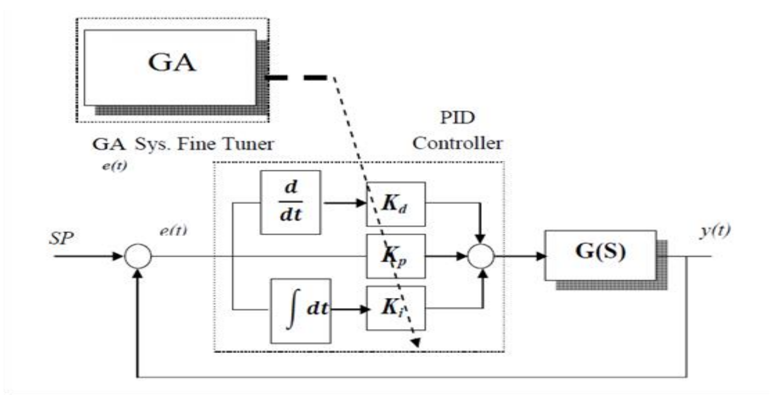

Figure 3. Structure of GA-PID Controller

Genetic Algorithms (GA.s) are a stochastic global search method that mimics the process of natural evolution. It is one of the methods used for optimization. John Holland formally introduced this method in the United States in the 1970 at the University of Michigan. The continuing performance improvement of computational systems has made them attractive for some types of optimization. The genetic algorithm starts with no knowledge of the correct solution and depends entirely on responses from its environment and evolution operators such as reproduction, crossover and mutation to arrive at the best solution. By starting at several independent points and searching in parallel, the algorithm avoids local minima and converging to sub optimal solutions. In this way, GAs have been shown to be capable of locating high performance areas in complex domains without experiencing the difficulties associated with high dimensionality, as may occur with gradient decent techniques or methods that rely on derivative information [12,13]. The convergence criterion of a genetic algorithm is a user-specified conditions for example the maximum number of generations or when the string fitness value exceeds a certain threshold. In this paper, the parameters to be used in the GA optimization are defined as followings:system overshoot=max(yout)-1, alpha=10 ;beta=10, The fitness function (to be minimized) is defined as: F=(de^2/dt^2) *beta+system overshoot*alpha ,the no of variables is three (K_p , K_I ,K_D) , the population type is double vector , population size is 20 , the initial range of variable is [0.2– 10] For the reproduction , the elite count is 2 and the crossover friction is 0.8 , the mutation function is Gaussian , the crossover function is scattered , the stopping rules is the no of generation is 100 , and the stall time limit is 200 sec.

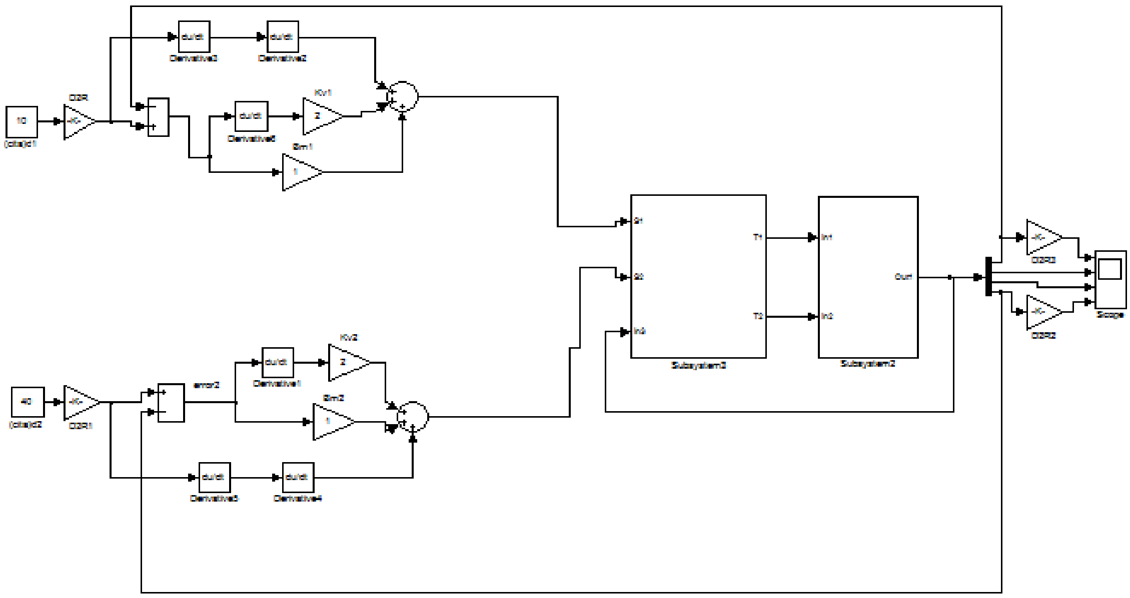

Figure 4. Detailed Structure of PID controller

4. FOPID based GA Controller

Fractional-order calculus is an area of mathematics that deals with derivatives and integrals from non-integer orders. This concept was proposed by Podlubny in 1997, it deals with derivatives and integrals from non-integer orders. In other words, it is a generalization of the traditional calculus that leads to similar concepts and tools, but with a much wider applicability. In the last two decades, fractional calculus has been rediscovered by scientists and engineers and applied in an increasing number of fields, namely in the area of control theory. The success of fractional-order controllers is unquestionable with a lot of success due to emerging of effective methods in differentiation and integration of non-integer order equations.

Fractional-order proportional-integral-derivative controllers have received a considerable attention in the last years both from academic and industrial point of view. In fact, they provide more flexibility in the controller design, with respect to the standard PID controllers, because they have five parameters to select (instead of three).

However, this also implies that the tuning of the controller can be much more complex. In order to address this problem, different methods for the design of a FOPID controller have been proposed. Further research activities are running in order to develop new tuning rules for fractional controllers, studying previously the effects of the non-integer order of the derivative and Integral parts to design a more effective controller to be used in real-life models. Some of these techniques are based on an extension of the classical PID control theory. The extension of differentiation and integration order from integer to non-integer numbers provides a more flexible tuning strategy and therefore an easier achieving of control requirements with respect to classical controllers. The fraction order controller form is given by the following equation [14-15]:

$$G_c(s) = k_p + \frac{k_i}{s^{\lambda}} + k_d\, s^{\mu} \tag{3}$$

The interest of this kind of controller is justified by a better flexibility, since it exhibits fractional powers (λ and μ) of the integral and derivative parts, respectively. Thus, five parameters can be tuned in this structure (λ; μ; k_p; k_i and k_d), that is, two more parameters than in the case of a conventional PID controller (λ = 1 and μ = 1). The fractional orders λ and μ can be used to fulfill additional specifications of design or other interesting requirements for the controlled system.

In this paper a simulation for a fractional-order system is done by using the frequency domain approximations, the fractional order equations of the system is first considered in the frequency domain and then Laplace form of the fractional integral operator is replaced by its integer order approximation then the approximated equations in frequency domain are transformed back into the time domain.The optimization work is done through using GA and Ninteger toolbox. Ninteger is a toolbox for MATLAB intended to help developing fractional-order controllers and assess their performance.This toolbox includes about thirty methods for implementing approximations of fractional-order and three identification methods. The Ninteger toolbox allows implementing, simulating and analyzing FOPID controllers easily via its functions. The most common form of a fractional order PID controller is the PIλDμcontroller. Involving an integrator of order λ and a differentiator of order μ where λ and μ can be any real numbers.
The transfer function of such a controller has the form:

$$G_c = \frac{U(s)}{E(s)} = k_p + k_I \frac{1}{s^{\lambda}} + k_D s^{\mu}, (\lambda\,, \mu > 0) \tag{4}$$

Where Gc(s) is the transfer function of the controller, E(s) is an error, and U(s) is controller's output. The integrator term is (1/ s^{λ}), that is to say, on a semi-logarithmic plane. The control signal u(t) can then be expressed in the time domain as:

$$u(t) = k_P e(t) + k_I D^{-\lambda} e(t) + k_D D^{\mu} e(t) \tag{5}$$

The block-diagram configuration of FOPID is presented in Figure (5). Clearly, selecting λ= 1 and μ = 1, a classical PID controller can be recovered. The selections of λ= 1, μ= 0, and λ= 0, μ= 1 respectively corresponds conventional PI & PD controllers. All these classical types of PID controllers are the special cases of the fractional PIλDμ controller.

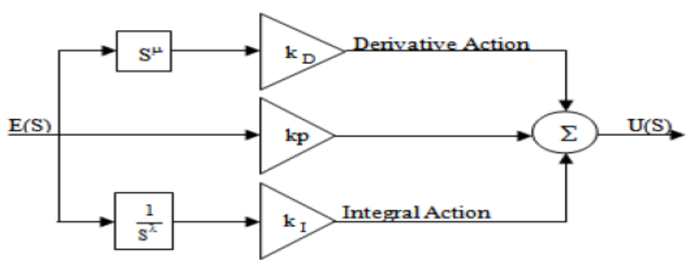

Figure 5. Block-diagram of FOPID

The analytic method, which lies behind the proposed tuning rules, is based on a specified desirable behavior of the controlled system; in this section the desirable dynamics described by the following criteria is only optimized through minimization the overall squared error, overshoot, rise time and settling time, which means that the response be as close as possible to the set point value along the time line till the steady state and leads to have a Zero steady-state error. The fitness function used for the GA will be square of error plus square of error differentiation

5. Fuzzy Logic for PID Controller

The fuzzy logic programming have been become widely used in industry. Extensive number of researches were developed using fuzzy logic technique. This paper proposed two inputs-three outputs self tuning of a PID controller. The controller design used the error and change of error as inputs to the self tuning, and the gains (KP1, KI1, KD1) as outputs. The FLC is adding to the conventional PID controller to adjust the parameters of the PID controller on-line according to the change of the signals error and change of the error. The controller proposed also contain a scaling gains inputs (Ke, KΔe) as shown in Figure 6, to satisfy the operational ranges (the universe of discourse) making them more general.

Now the control action of the PID controller after self tuning can be describing as:

$$U_{PID} = K_{P2} * e(t) + K_{I2} \int e dt + K_{d2} \frac{de(t)}{dt} \quad (6)$$

Where KP2, KI2, and KD2 are the new gains of PID controller and are equals to:

KP2=KP1 * KP, KI2=KI1 * KI, and KD2=KD1 * KD (7)

Where KP1, KI1, and KD1 are the gains outputs of fuzzy control that are varying online with the output of the system under control. And KP, KI, and KD are the initial values of the conventional PID. In this paper, the fuzzy logic controller is used for PID parameter adaptation and is different than that used in [14] which use the fuzzy controller like PD controller.

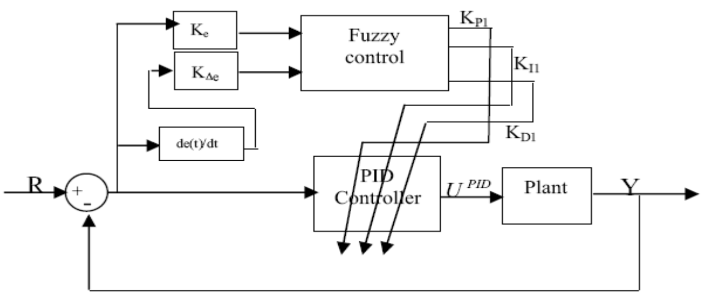

Figure 6. Proposed Fuzzy Self Tuning

The general structure of fuzzy logic control is represented in Figure 13 and comprises three principal components:

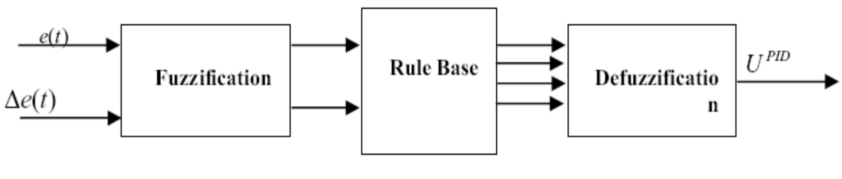

Figure 7. Fuzzy Logic Control Structure

1. Fuzzification this converts input data into suitable linguistic values. As shown in Figure 7, there are two inputs to the controller: error and rate change of the error signals. The error is defined as e(t) = r(t) - y(t) , Rate of error is defined as ∆e(t)=de(t)/dt , Where r (t) is the reference input, y (t) is the output, e(t) is the error signal, and ∆e(t) is the rate of error. The seventh triangular input and output member ship functions of the fuzzy self tuning are shown in the Figures 8 and 9. For the system under study the universe of discourse for both e(t) and ∆e(t) may be normalized from [-1,1], and the linguistic labels are {Negative Big (NB), Negative medium (NM), Negative small (NS), Zero(Z), Positive small (PS), Positive medium (PM), Positive Big(PB) } ,and the linguistic labels of the outputs are {Zero(Z),Zero Negative (ZN), Medium small (MS), Small(S), Medium(M), Big(B), Medium big(MB), very big(VB)} and referred to in the rules bases as {Z,.MS, S, M, B, MB, VB}.

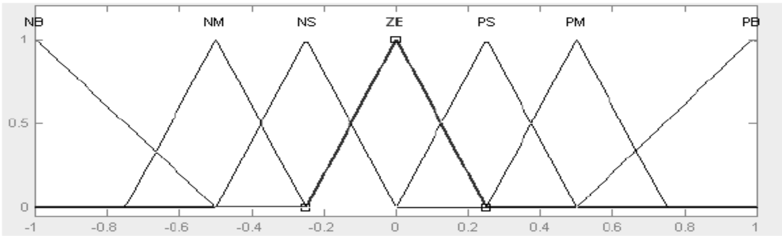

Figure 8. Memberships Function of Inputs (e, ∆e)

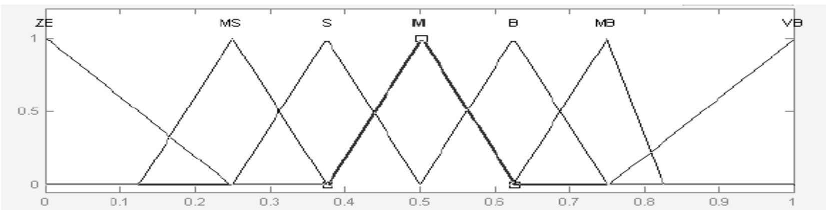

Figure 9. Memberships Functions of Outputs (KP1, KI1, and KD1).

Table 1. Rule Base for Determiningthe Gain KP1

ė/e	NB	NS	ZE	PS	PB
NB	VB	VB	VB	VB	VB
NS	B	B	B	MB	VB
ZE	ZE	ZE	MS	S	S
PS	B	B	B	MB	VB
PB	VB	VB	VB	VB	VB

Table 2. Rule Base for Determiningthe GainKI1

ė/e	NB	NS	ZE	PS	PB
NB	M	M	M	M	M
NS	S	S	S	S	S
ZE	MS	MS	ZE	MS	MS
PS	S	S	S	S	S
PB	M	M	M	M	M

2. Rule base: A decision making logic which is, simulating a human decision process, fuzzy control action from the knowledge of the control rules and linguistic variable definitions.

Where Ei and Ej are the linguistic label input, UP, UI, and UD are the linguistic label output. Tables (1), (2), and (3) show the control rules that used for fuzzy self tuning of PID controller.

Table 3. Rule Base for Determiningthe Gain KD1

ė/e	NB	NS	ZE	PS	PB
NB	ZE	S	M	MB	VB
NS	S	B	MB	VB	VB
ZE	M	MB	MB	VB	VB
PS	B	VB	VB	VB	VB
PB	VB	VB	VB	VB	VB

3. Defuzzification: This yields a non fuzzy control action from inferred fuzzy control action. The most popular method, center of gravity or center of area is used for defuzzification.

6. Fuzzy Logic FOPID Based GA Controller

The construction of fuzzy logic FOPID is shown in Figure 10.

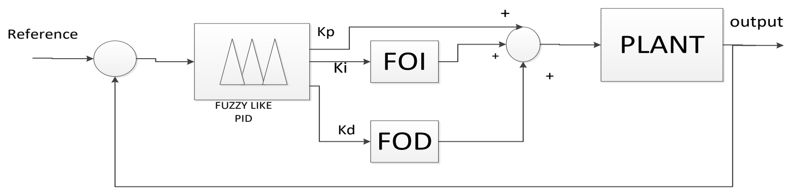

Figure 10. Fuzzy FOPID Construction

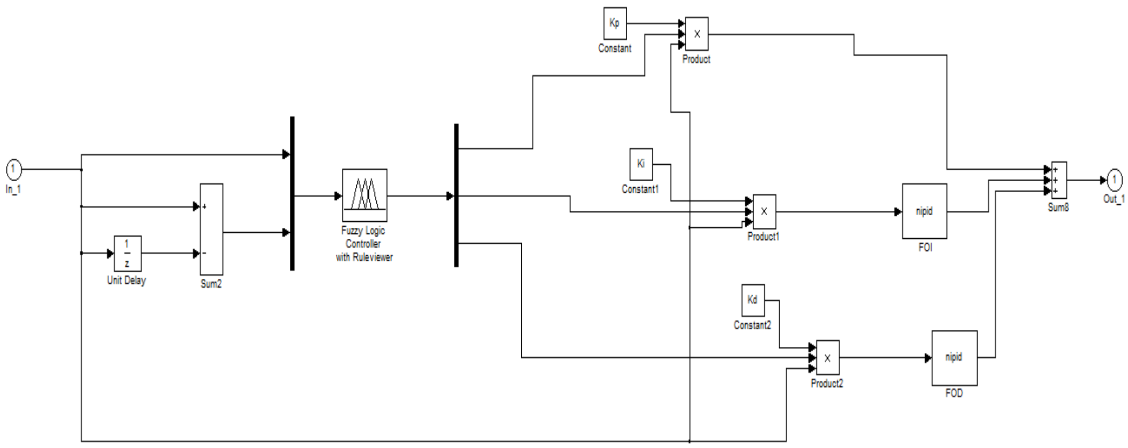

Figure 11. Fuzzy FOPID construction in MATLAB Simulink

For the fuzzy FOPID, we are using the same fuzzy logic described before used with the conventional PID with adding Fractional Order Integeral (FOI) with the term of Ki fuzzy output and Fractional Order Derivative (FOD) with the term of Kd fuzzy output. The transfer function of FOI will be $G_c(s) = \frac{k_i}{s^{\lambda}}$, while the transfer function of FOD will be: $G_c(s) = k_d\, s^{\mu}$

The construction of fuzzy FOPID controller using MATLAB Simulink is indicated in Figure 11. The tuning of FOI and FOD parameters will be done using GA with the same fitness functions indicated above.

7. Simulation Results

This section presents the compared output response after usingPID based ZN, PID based on fuzzy logic, FOPID based GA, fuzzy FOPID based on GA. Two different position references are used for simulation; the reference for the first motor will be 10^{e} whilethe second reference will be 40^{e}.The PID parameters in the studied cases are shown in Table 4.

Table 4. Values of controller parameters in different studied cases

Parameters	P	I	D	λ	μ
ZN	2	0.01	1	0	0
Fuzzy Logic	0.943	0.0023	0.5	0	0
FOPID based on GA	16.4781	5.0936	21.7778	0.8963	0.8963
FOPID based on GA (FOI)	0	6	0	1	0
FOPID based on GA (FOD)	0	0	14.438	0	0.8723

The simulation results are presented as shown in Figure 12 to Figure 15 for two DC motors driving system working together to track a predefined position (10θ and 40θ) for each motor. The results shown in the below figures shows that the fuzzy FOPID give the best performance for the reference tracking , while the FOPID based GA is better than the fuzzy logic controller like PID. The fuzzy logic controller like PID has better performance than the PID based ZN.

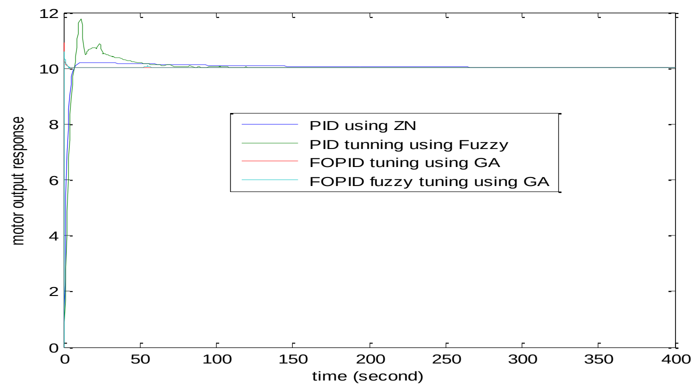

Figure 12. First motor output response

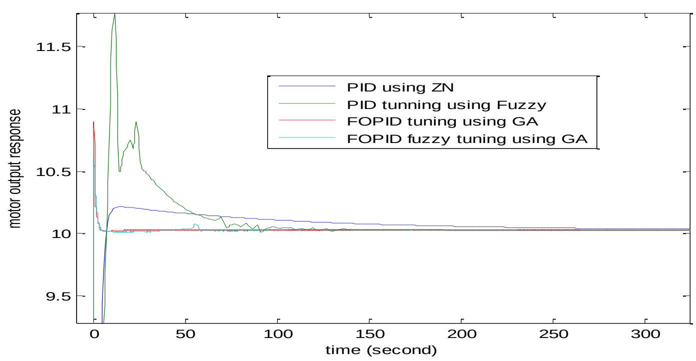

Figure 13. First motor output response after amplification

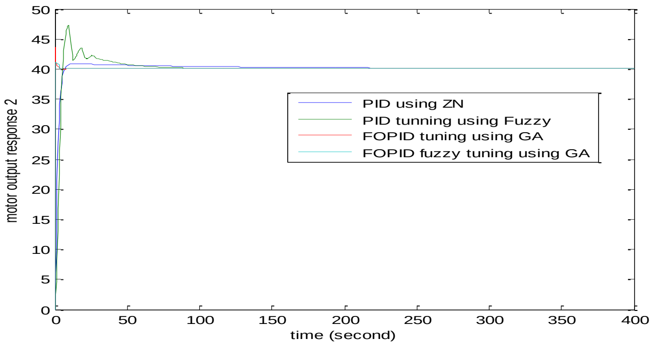

Figure 14. second motor output response

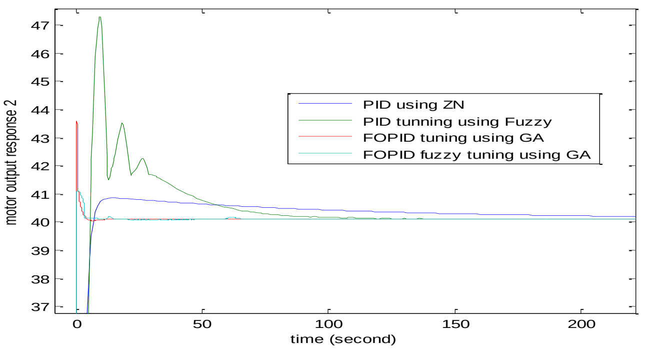

Figure 15. Second motor output response amplification

8. Conclusion

In this work, we are using the PID controller for the telescope nonlinear tracking system as an application. There are many studies which are implemented on the conventional type of the PID controller, while we are using one of the most recent techniques which are known as fractional order PID controller. Fuzzy logic controller was applied to be like conventional PID controller while in this paper, fuzzy FOPID controller is used to improve the dynamic performance of the FOPID controller. The simulation results show that the performance of the FOPID is better than the conventional PID controller, while the performance is become more better by adding the fuzzy logic to the FOPID controller which is known as fuzzy FOPID controller.

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