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Efficient Fractional Feedback Speed Controller in DC Motor Using FOPID Fed with PSO

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Abstract: ***In this paper, we introduced the much efficient dc motor speed Controller by using fractional feedback FOPID method. in simple PID we can change only gains of the proportional, derivative and integral controller. In FOPID method there are two more variable mu (μ) and lambda (λ) that we can adjust for obtaining faithful result. Here fractional feedback FOPID is used in placed of unity feedback for obtaining better performance. In which there are six variables that are three gains, two constant mu (μ) and lambda (λ) and one feedback constant is beta (β). This paper will also give little view of particle swarm optimization by which we get optimized value of variable at which best result will occur.***

Keywords: DC Motor, PSO, Fractional order PID controller, Fractional feedback FOPID controller

1. Introduction

DC motor being a power actuator, converts electrical energy into rotational mechanical energy. DC motors are widely used in industry and commercial application such as tape motor, disk drive, robotic manipulators and in numerous control applications. Therefore, its control is very important. For the control of dc motor, traditional controllers such as PI and PID controller have been used widely in literature. In this paper, DC motor is controlled by a non-conventional control technique known as a fractional-order PID (FOPID) control. This technique was developed during the last few decades and it has various practical applications viz. Flexible spacecraft attitude control, Car suspension control, temperature control, motor control etc.[1][3] This idea of the fractional calculus application to control theory has been described in many other works and its advantages are proved as well.

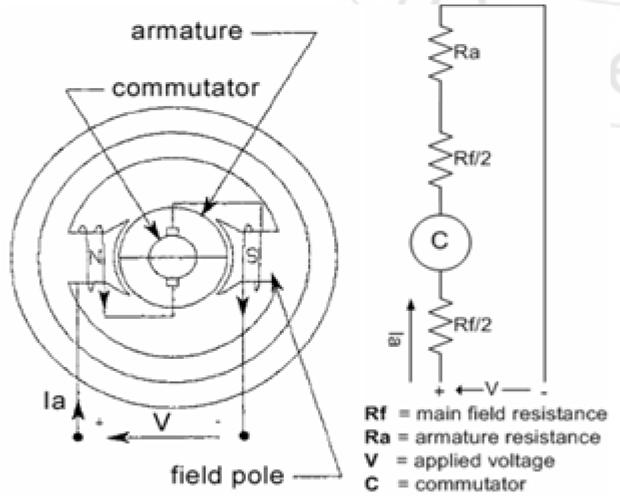

Figure 1: DC Motor structure

Proportional–Integral-Derivative (PID) controllers have been used for several decades in industries for process control applications. The reason for their wide popularity lies in the simplicity of design and good performance including low percentage overshoot and small settling time for slow process plants. The mnemonic PID refers to the first letters of the names of the individual terms that make up the standard three-term controller. These are P for the proportional term, I for the integral term and D for the derivative term in the controller. Three-term or PID controllers are probably the most widely used industrial controller. Even complex industrial control systems may comprise a control network whose main control building block is a PID control module.[1]

2. DC Motor

The speed of a DC motor can be varied by controlling the field flux, the armature resistance or the terminal voltage applied to the armature circuit. The three most common speed control methods are field resistance control, armature voltage control, and armature resistance control. In this section, we model the transfer function of an armature controlled DC motor for its speed control so as to study the control performance of Fractional order PID controller.[10][5]

In the armature voltage control method, the voltage applied to the armature circuit, e_a is varied without changing the voltage applied to the field circuit of the motor. Therefore, the motor must be separately excited to use armature voltage control. The electrical equivalent diagram of an armature controlled DC motor is given in the figure below.

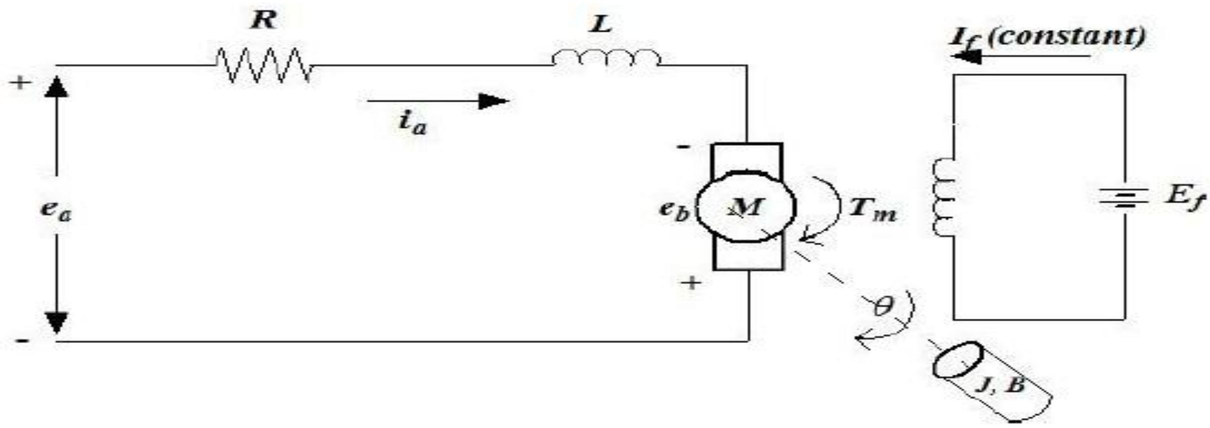

Figure 2: Equivalent circuit diagram

where
R = armature resistance (Ω),
L = self inductance of armature (H),
i_a = armature current (A),
i_f = field current (A),
e_a = applied armature voltage (V),
e_b = back emf (V),
T_m = torque produced by the motor (Nm),
θ = angular displacement of motor shaft (rad),
ω = angular speed of motor shaft (rad/sec),
J = equivalent moment of inertia of motor and load referred to motor shaft (kg-m^2),
B = equivalent viscous friction coefficient of motor and load referred to motor shaft (Nm*s/rad).

DC motors when applied in servo applications are generally used in the linear range of magnetization curve.Hence, the air gap flux ϕ is proportional to the field current, i.e.

$$\phi = K_f\, i_f \tag{1}$$

where K_f is constant.

The torque T_m developed by the motor is proportional to the product of armature current and air gap flux, i.e.

$$T_m = K_1 K_f\, i_f\, i_a \tag{2}$$

Here K_1 is constant.Since the field current is constant in armature controlled DC motor,so $T_m = K_T\, i_a$.Here K_T is the motor torque constant.The motor back e.m.f e_b is proportional to speed i.e.

$$E_b = K_b\, \omega = K_b \frac{d\theta}{dt} \tag{3}$$

Here K_b is back e.m.f constant.

Now writing the KVL equation for the armature circuit we get,

$$L\frac{di_a}{dt} + R\, i_a + e_b - e_a = 0 \tag{4}$$

And the torque equation is

$$J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} = T_m = K_T\, i_a \tag{5}$$

Applying Laplace Transform

$$e_b(s) = K_b\, s\, \theta(s) \tag{6}$$

$$(Ls+R)I_a(s) = e_a(s) - e_b(s) \tag{7}$$

$$(Js^2 + Bs)\, \theta(s) = T_m(s) = K_T i_a(s) \tag{8}$$

Finally, the transfer function of DC motor is given by:

$$G_p(s) = \frac{s\cdot\theta(s)}{E_a(s)} = \frac{\omega(s)}{E_a(s)} = \frac{k_T}{[(R+Ls)(Js+B)+k_T K_b]} \tag{9}$$

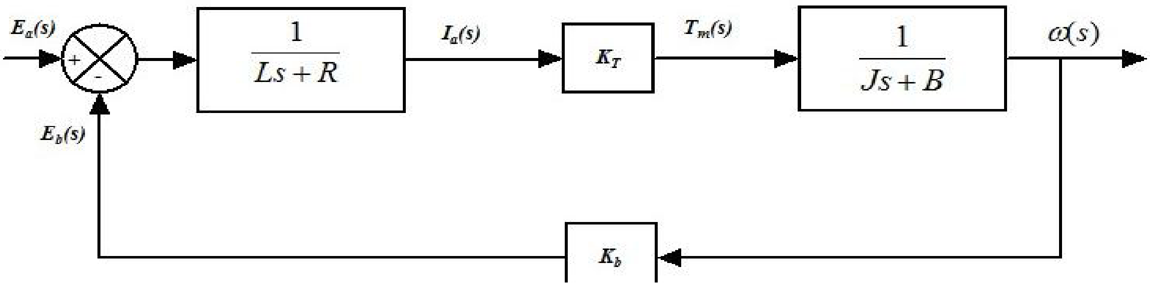

Figure 3: Block diagram of DC Motor

After applying the parameter values of DC motor as given in the appendix A, the final transfer function of DC motor becomes

$$G_p(s) = \frac{0.01}{0.005s^2 + 0.06s + 0.1001} \tag{10}$$

3. Modelling of DC Motor in MATLAB

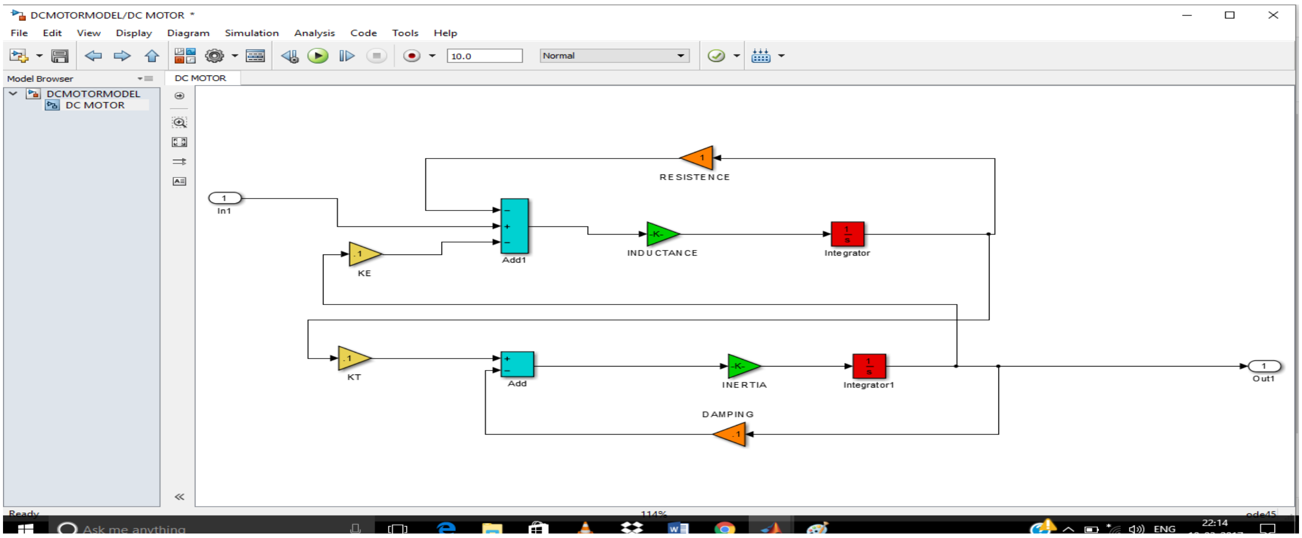

Figure 4: MATLAB Model of DC Motor

4. PID Controler

A PID controller is essentially a generic closed loop feedback mechanism.The controller monitors the error between a measured process variable and a desired set point. From this error, a corrective signal is computed and is eventually feedback to the input side to adjust the process accordingly. The controller attempts to minimize the error by adjusting the process control inputs.[6]

The differential equation of a PID controller is given by:

$$U(t) = K_p \cdot e(t) + K_i \int_0^t e(t)dt + K_d \frac{d}{dt} e(t) \quad (1)$$

and the transfer function of the controller is given by:

$$G_{PID}(s) = K_p + \frac{K_i}{s} + s \cdot K_d \quad (2)$$

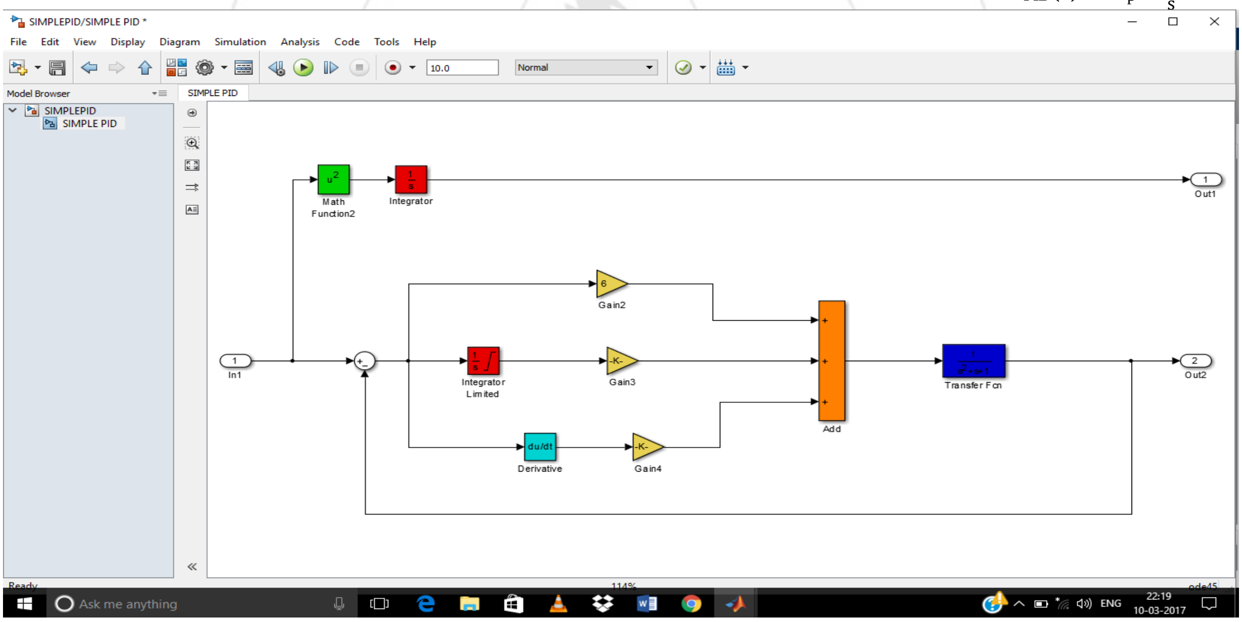

Figure 5: MATLAB model of Simple PID Controller

5. FOPID

Fractional Order PID controller denoted by **$PI^{\lambda}D^{\mu}$**was proposed by Igor Podlubny in 1997. It is an extension of Conventional PID Controller where λ and μ have fractional values. shows the block diagram of fractional order PID controller.[2]

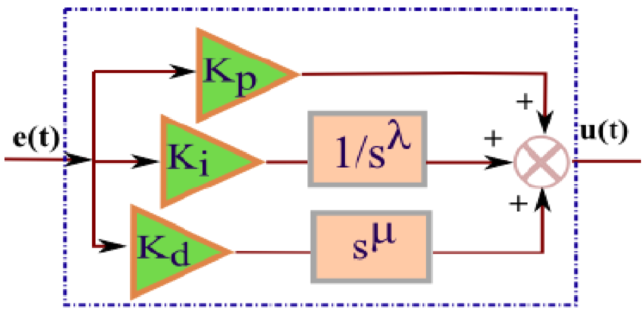

Figure 6: Basic Block diagram of FOPID

The integro-differential equation defining the control action of a fractional order PID controller is given by:

$u(t) = K_p\, e(t) + K_i\, D^{-\lambda}\, e(t) + K_d\, D^{\mu}\, e(t)$ (1)

and thus the transfer function of the controller becomes

$G_{FOPID}(s) = K_P + \frac{K_i}{s^{\lambda}} + K_d \cdot s^{\mu}$ (2)

where λ and μ are an arbitrary real numbers.

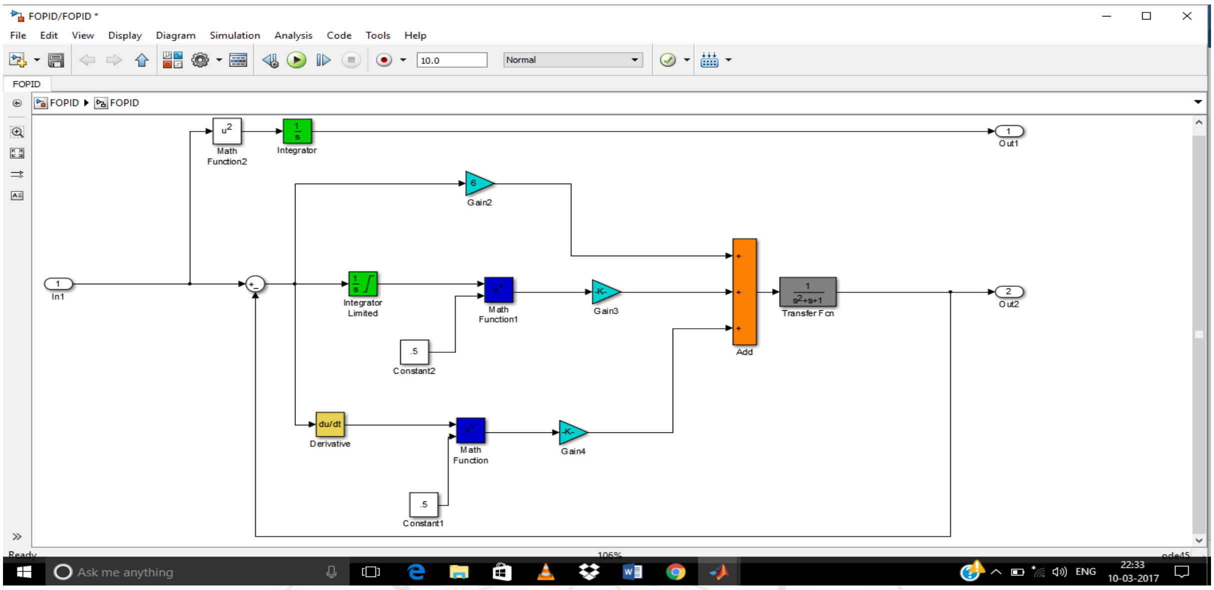

Figure 7: MATLAB model of FOPID

6. Proposed Model

In this paper we are introduce fractional feedback speed controller of dc motor by changing the gain of feedback path. In fractional order PID controller we five variables that we can adjusted for obtain appropriate result. Here we have one more variable 'chi' that we can change for getting better result.[9]

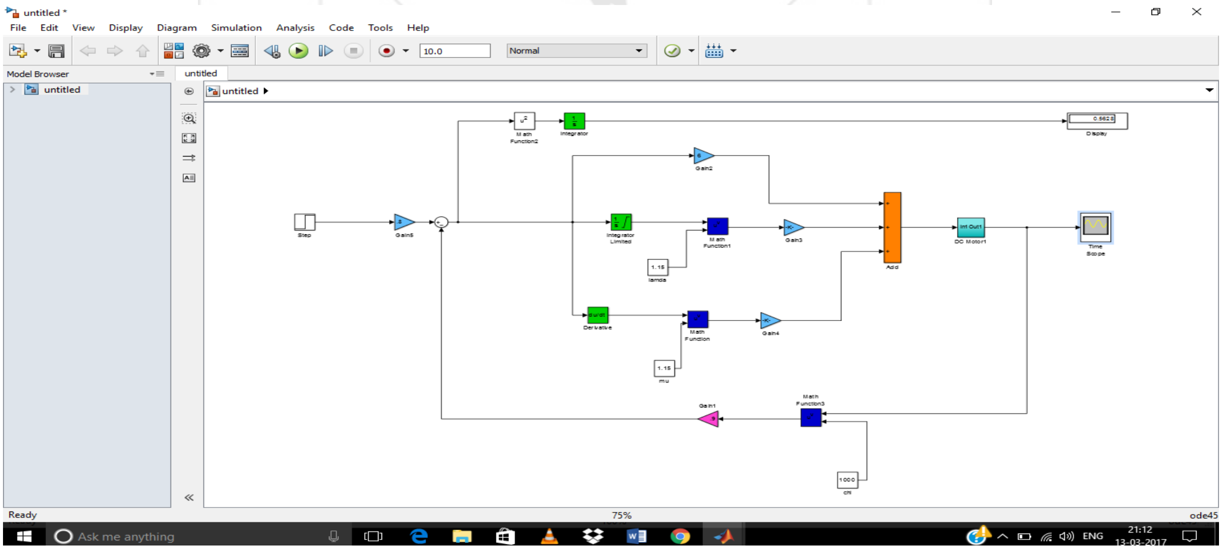

Figure 8: MATLAB model of Fractional feedback FOPID

7. Result

1: Simple PID

This chapter shows the results obtained for unit step response of DC motor using classical PID controller and fractional order PID controller in MATLAB.These results are accompanied by the tables showing various performance parameters. Optimization of FOPID has been done using particle swarm optimization and finally the optimal FOPID has been compared with classical one. Classical PID controller is tuned by Ziegler-Nicholas method and we obtained the following:

Proportional gain $K_p = 6$

Integral gain $K_i = 28.3$

Derivative gain $K_d = 0.318$

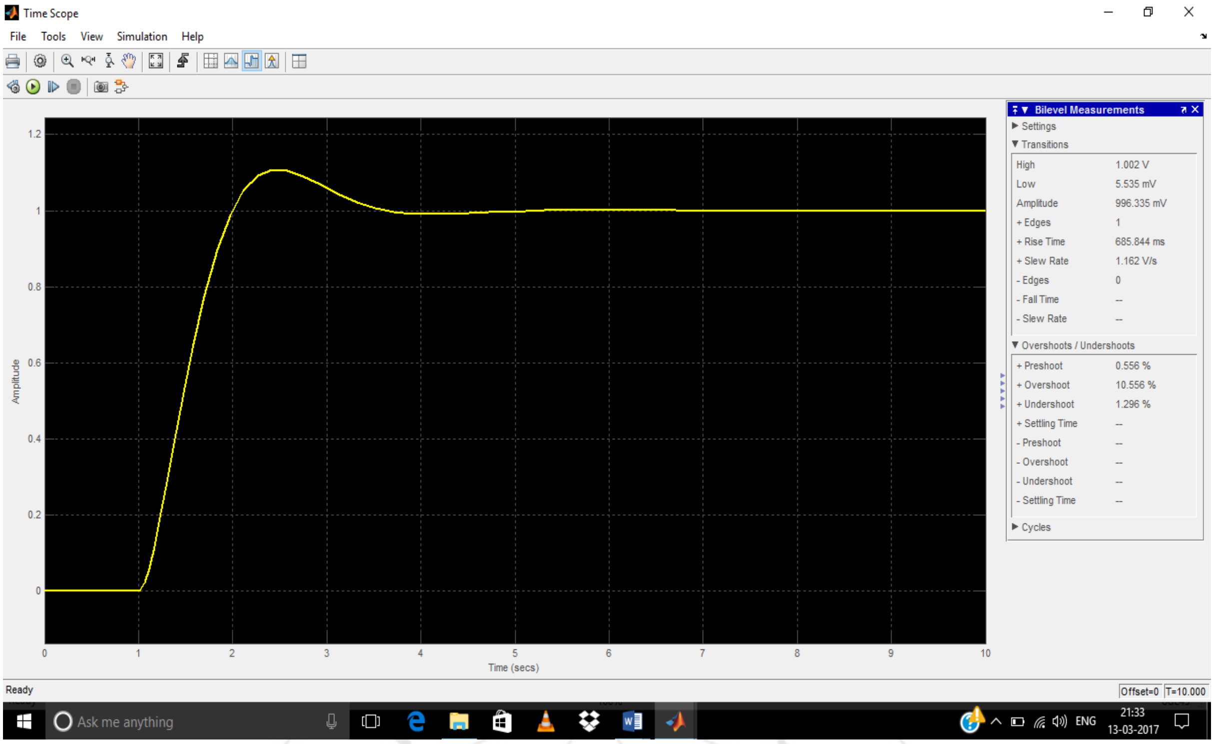

Figure 9: Unit Step Response of DC Motor using PID Controller

Table 1: Parameters for PID Control

Proportional Gain K_p	Integral Gain K_i	Derivative Gain K_d	Peak Overshoot (%)M_p	Peak Time (sec)T_p	Settling Time (sec)T_s	Integral Square ErrorISE
6	28.3	0.318	10.556	2.47	3.1	0.3449

2: Fractional order PID

The unit step responses and control performance of FOPID controller for different combinations of λ and μ is shown below. These graphs show the step responses of system with fractional PID controller, where the derivative order μ and integral order λ are in fractions. The fractions can be less than or greater than 1.We take eight different combinations of λ and μ as follows:

a) With varying values of λ<1 and μ<1

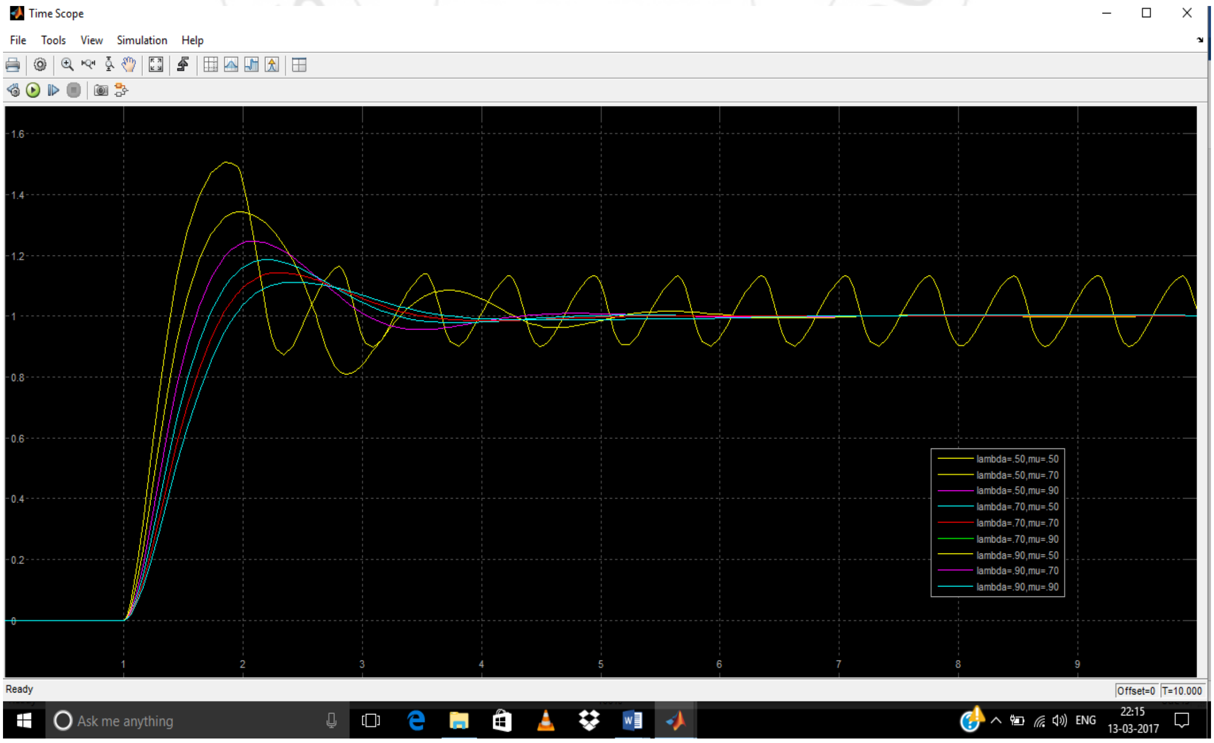

Figure 10: Comparison of Parameters for Different Combinations of λ<1 and μ<1

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Table 2: Comparison of Parameters for Different Combinations of λ<1 and μ<1

Integral Orderλ	Derivative Orderμ	Peak Overshoot (%)M_p	Peak Time (sec)T_p	Settling Time (sec)T_s	Integral Square Error ISE
0.5	0.5	26.5058	2.1536	3.5961	0.286
0.5	0.7	26.7243	2.1446	3.6187	0.2864
0.5	0.9	26.9232	2.1085	3.4517	0.2869
0.7	0.5	19.0836	2.1777	2.9069	0.3041
0.7	0.7	19.2968	2.3212	3.0267	0.3044
0.7	0.9	19.6501	2.2879	2.8258	0.3048
0.9	0.5	15.0713	2.3615	3.0890	0.3312
0.9	0.7	15.1803	2.3340	3.0644	0.3313
0.9	0.9	15.1968	2.4555	3.0036	0.3315

b) With varying values of λ>1 and μ>1

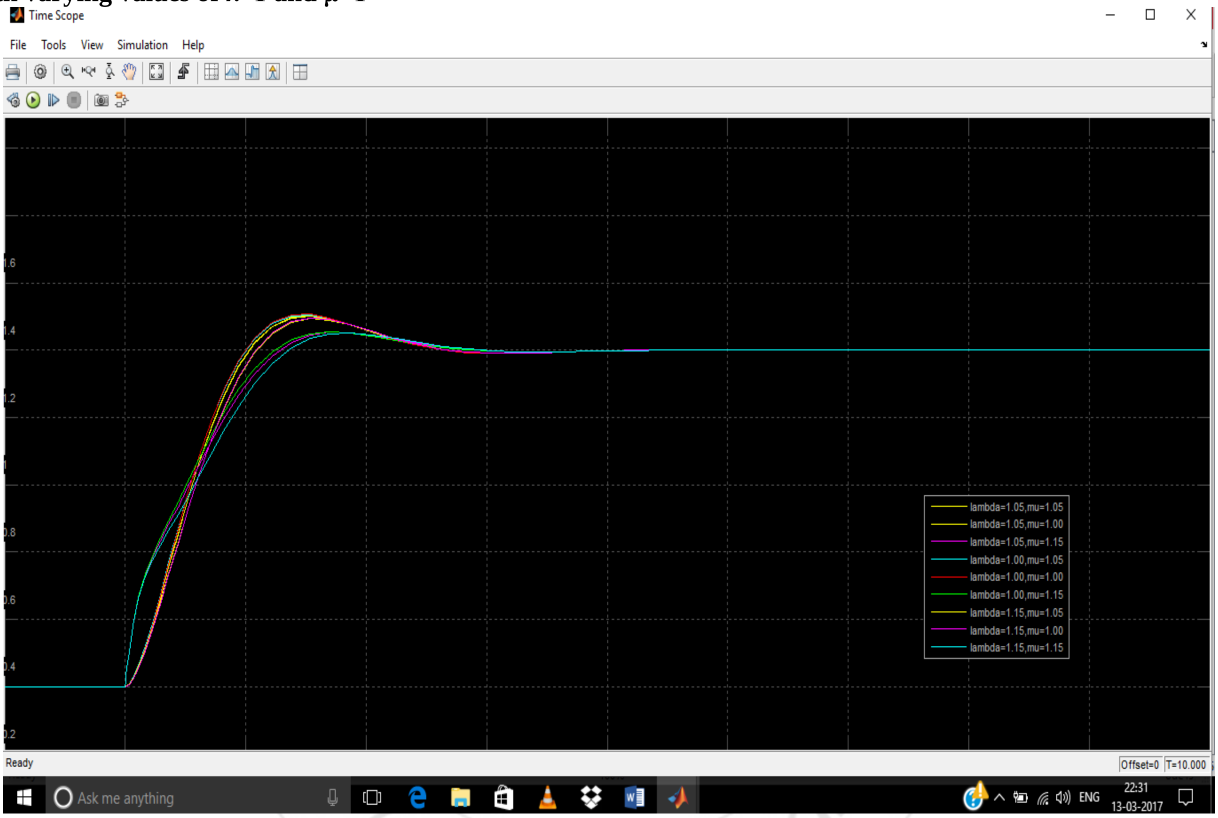

Figure 11: Unit Step Response of DC Motor using FOPID Controller for Varying Values of λ > 1 and μ > 1

Table 3: Comparison of Parameters for Different Combinations of λ>1 and μ>1

Integral Order λ	Derivative Order μ	Peak Overshoot (%)M_p	Peak Time(sec) T_p	Settling Time(sec) T_s	Integral Square ErrorISE
1.05	1.05	13.2209	2.4806	3.0514	0.3479
1.05	1.1	11.8799	2.4159	2.9683	0.327
1.05	1.15	7.1071	2.7573	2.9573	0.237
1.1	1.05	12.7180	2.4831	3.0413	0.355
1.1	1.1	11.5889	2.5615	2.9388	0.3342
1.1	1.15	6.9922	2.7544	2.9544	0.2445
1.15	1.05	12.2015	2.4725	3.0215	0.3621
1.15	1.1	11.2334	2.5383	3.0984	0.3413
1.15	1.15	4.8675	2.7519	2.9519	0.252

3: Fractional feedback with FOPID

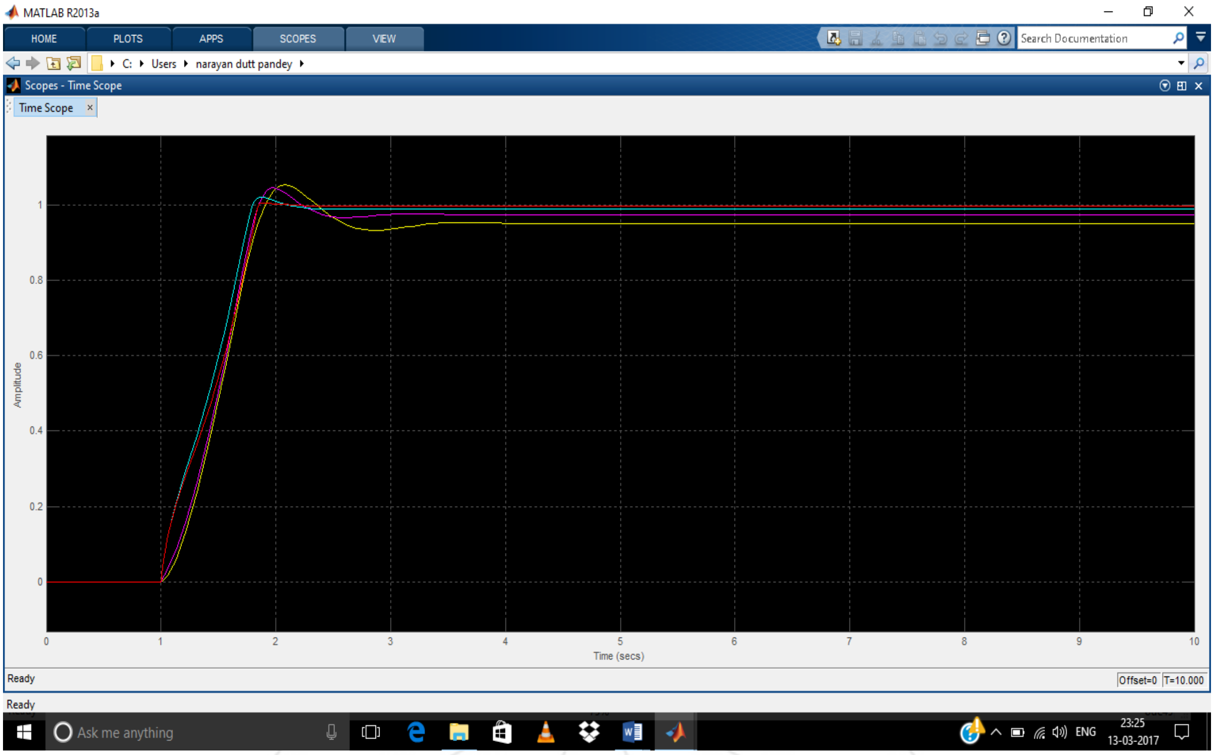

Figure 12: Unit Step Response of DC Motor using FOPID Controller for Varying Values of λ, μ and β

Table 4: Comparison of Parameters for Different Combinations of λ, μ and β

Integral Order λ	Derivative Order μ	Beta β	Peak Overshoot (%) M_p	Peak Time (sec) T_p	Settling Time (sec) T_s	Integral Square Error ISE
1	1.05	5	10.7526	2.1785	3.6580	0.3807
1	1.1	10	6.5777	1.9209	3.1814	0.3198
1	1.15	25	3.6822	1.8730	2.3606	3.7856
1.15	1.15	50	1.1108	1.8502	2.5068	0.3894
1.15	1.15	100	0.5058	1.8920	3.7025	0.2972

8. Implementation of Particle Swarm Optimization

The parameter values taken for running the PSO algorithm in MATLAB environment is given in table below:

Table 5: PSO parameter values

Parameter	Values
Number of Particles	50
Maximum no. of Iterations	100
Cognitive Component C_1	2
Social Component C_2	2
Maximum Speed	10
Minimum Inertia Weight (W_{min})	0.4
Maximum Inertia Weight(W_{max})	0.9

After running the PSO algorithm as a MATLAB script file given in the appendex for different combinations of λ and μ, we obtain the following solution set which gives the most optimal parameter values of the controller in the defined search space.[4][6]

[λ μ β] = [M_p T_p T_s ISE] : [1.15 1.15 100] = [.5052 1.89 2.7025 0.2972]

After getting the optimal values of λ, μ and β,we compare the unit step response of optimal FOPID controller and classical PID controller as shown in fig 14.

Figure 13: Comparison of Performance Parameters of PID, FOPID and Fractional Feedback FOPID Controller

Table 6: Comparison of Performance Parameters of PID, FOPIDand Fractional Feedback FOPID Controller

Controller	Peak Overshoot (%)M_p	Peak Time (sec)T_p	Settling Time (sec)T_s	Integral Square ErrorISE
PID	12.87	2.47	3.1	0.3449
Optimal FOPID	6.87	2.75	2.95	0.252
Fractional Feedback FOPID	0.5058	1.8920	2.7025	0.2972

From the above graph and table, it is clear that Fractional Feedback FOPID controller largely reduces the peak overshoot obtained by Simple PID controller. It also improves the settling time and integral square error and thus, enhances the control performance.

9. Conclusion

According to the analysis done on the basis of results obtained through MATLAB/SIMULINK, we have landed to a conclusion that the Fractional feedback FOPID controller is more flexible than the conventional PID controller and gives an opportunity to better adjust the dynamics of control system. Fractional calculus can provide novel and higher performance extension forFractional feedback FOPID controllers. It improves the performance characteristics and provides flexibility and robust stability as compared to the classical one applied to the DC motor owing to the two extra tuning parameters i.e. order of integration and order of derivative in addition to proportional gain, integral time and derivative gain. Particle swarm optimization has been successfully applied to the controller to obtain the optimal values of the parameters, thus, enhancing the control performance.

10. Future Scope

Fractional feedback FOPID controller being more flexible than its integer counterpart can be applied to other type of plants such as in cruise control, inverted pendulum, ball suspension, etc to enhance its control performance. Many other optimization techniques such as genetic algorithm, ant colony optimization, neural networks, fuzzy logic, adaptive control and hybrid of these techniques can also be applied to optimize the controller parameters.

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