COMPARISON OF SIMULINK BASED FOPID AND PID CONTROLLER

Amrit Kaur[1], Ranjit Kaur[2]

[1,2] Department of Electronics and Communication Engineering

Email: [1]amrit_aks@yahoo.ca,[2]ranjit24_ucoe@pbi.ac.in

Abstract: A controller is a device that is used to regulate the behavior or response of a process so as to get desired response.PID controllers are used in almost all industries because of its simplicity, clear functionality and broad applicability. However, PID tuning if done manually and using traditional techniques is one of the obstacle for having efficient control. Research is going on in Fractional calculus, fuzzy, neural and other optimization techniques to improve its tuning. This paper presents the comparison of simulink based FOPID and PID controller for three different processes by implementing on 1st order, higher order and inverted pendulum systems. It has been found that the results show the superiority of FOPID controller over PID controller.

Keywords: Classical PID, FOPID, Fuzzy PID, Benchmark systems, FOMCON toolbox

1. Introduction

Controllers play an important part in process industries. Since invention of PID control in 1910 (largely owning to Elmer Sperry's ship autopilot), and the Ziegler–Nichols' (Z-N)straight forward tuning methods in 1942 [1], the popularity of PID control has grown tremendously. Today, the PID controllers are the most sought after feedback controllers used in more than 90% of industries. The main requirement of all the controllers is to design them in such a way so that the process variables are always close to desired value[2-3]. There is so much of research going on in obtaining this requirement using different tuning methods. PID controller tuning was first considered complicated because of the presence of inherent non-linearities in the plant dynamics and various uncertainties such as modelling error, measurement noise and external disturbances involved in the system. Thus, poor tuning can lead to poor control performance and even poor quality products. Several approaches are reported in literature for tuning the parameters of PID controllers. Ziegler-Nichols (ZN), Cohen-Coon (CC) and internal model control(IMC) are the most commonly used closed loop analytical methods for tuning PID controllers. [2-3]

Recently, many researchers have worked on the tuning of different structures of PID such as IPD and D-PI and found that Zeigler Nicholas is only applicable on parallel PID structure and the Z-N method rules should be refined to apply to other structures[4-5].Then with the advent in the research of artificial intelligence techniques, researchers started implementing fuzzy PID controller and its various configurations like hybrid and TI, SI etc which gave better performance than the classical PID controller[6-7]. Some of the research concentrated on comparing the result of PID and fuzzy PID controller to prove the superiority of Fuzzy PID[8]. Research was also going on in the field of combining fractional calculus and PID controller to give it the name Fractional order PID (FOPID) controller or $PI^{\lambda}D^{\mu}$. Till date more than 100 researchers have found that adding fractional order to PID controller has made it superior in performance, more robust and more flexible than the integral PID controller because of the increased degrees of freedom in FOPID. There are only three degrees of freedom Kp, Ki and Kd in integer PID whereas five in FOPID namely Kp,Ki,Kd,λ and μ. But because of increased parameters the tuning becomes a little complex[9-12].Alongside this research was blooming the concept of optimization using nature inspired techniques categorized as bio- inspired such as GA ,Swarm type like PSO or physics and chemistry inspired optimization techniques based on the source of inspiration for such algorithms to reach their global best[13].All the above described controllers were also optimized by various researchers using Genetic algorithm, ABC, BAT, Differential, Bacterial Foraging, Cuckoo search, ant colony and with the hybridization of these techniques also. Depending on the problem and the objective functions it has been found that PSO and its Hybrid Model AVUPRSO are better than GA and ant colony. While Cuckoo has outperformed PSO in recent search [13-21].

2. PID Controller

During the 1930s three mode controllers with proportional, integral, and derivative (PID) actions became commercially available and gained widespread industrial acceptance. These types of controllers are still the most widely used controllers in process industries.the transfer function of PID controller is:

$$Gc(s) = Kp + \frac{Ki}{s} + sTd \qquad (1)$$

Kp=proportional gain

Ki=integral constant

Kd= Derivative time

3. Fractional Calculus

Fractional-order calculus is an area of mathematics that 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.

The differ integral operator, denoted bya $D^q t$, is a combined differentiation-integration operator commonly used in fractional calculus. This operator is a notation for taking both the fractional derivative and the fractional integral in a single expression and is defined by

$$aD_t^q = \begin{cases} \frac{d}{dt} & q > 0 \\ 1 & q = 0 \\ \int (d\tau)^{-q} & q < 0 \end{cases} \quad (2)$$

Where q is the fractional order which can be a complex number and a and t are the limits of the operation. There are some definitions for fractional derivatives. The commonly used definitions are Grunwald–Letnikov, Riemann–Liouville, and Caputo definitions The Riemann–Liouville definition is the simplest and easiest definition to use but it appears unsuitable to be treated by the Laplace transform technique because it requires the knowledge of the non-integer order derivatives of the function at t = 0 . This problem does not exist in the Caputo definition that is sometimes referred to as smooth fractional derivative. In literature definition of Caputo derivative is defined by

$$D_t^q = \left\{\frac{1}{\Gamma(m-q)} \int_0^t \frac{f^{(m)}(\tau)}{(t-\tau)^{q+1-m}} d\tau\right\} m-1 < q<m$$

$$\left\{\frac{d^m}{dt^m} f(t)\right\} q = m \quad (3)$$

The Laplace transform of the Caputo fractional derivative (2) is

$$L\left\{\{oD_t^q f(t)\}\right\} = s^q F(s) - \sum_{k=0}^{n-1} s^{q-k-1} f^k(0) n - 1 < q < n \in N \quad (4)$$

For zero initial conditions, Eq. (3) reduces to (4) [21].

$$\{0D_t^q f(t)\} = s^q F(s) \quad (5)$$

4. FOPID Controller

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. With FOPID the area of applicability has increased as can be seen from fig.1.

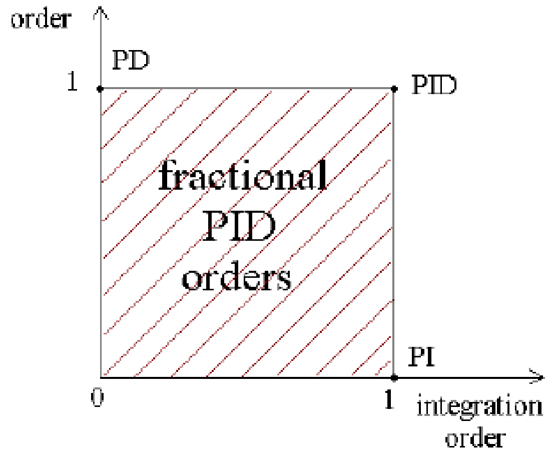

Fig.1 expanding from point to plane

The transfer function of FOPID controller is given by:

$$Gc(s) = Kp + Tis^{-\lambda} + s^{\mu}T_d \qquad (6)$$

5. Design Problem

In industries the processes are of various types; they can be categorized as 1st order,2nd n order ,higher order, unstable, with time delay,with load disturbance, set point variations ,noise etc depending from process to process where the particular controller is to be implemented. We have taken three benchmark systems:1st order with time lag 0.5, higher order and inverted pendulum example which comes under the unstable processes. These three systems are simulated using MATLAB/SIMULINK and FOMCON toolbox and the results are compared in all these examples.

Example 1 1st order system with time lag 0.5

$$G(s)= \frac{1}{1+0.5s}$$

The simulink for this process as unity feedback system(fig.2) with PID(fig.3)where Kp=3,Ki=1,Kd=10 and with FOPID(Fig.4) Kp=2,Ki=2,Kd=10,λ=0.7, μ=0.9 are shown below

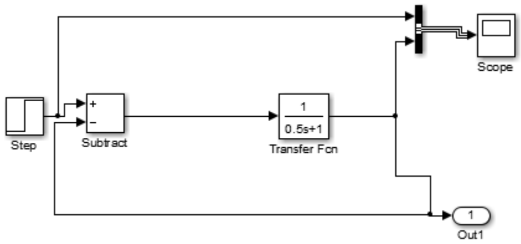

Fig.2 1st order unity feedback system with T=0.5 with unit step input

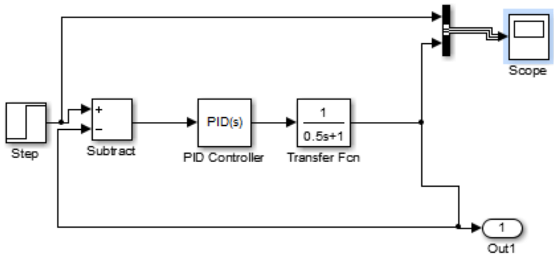

Fig.3 1st order unity feedback system with T=0.5 and PID controller

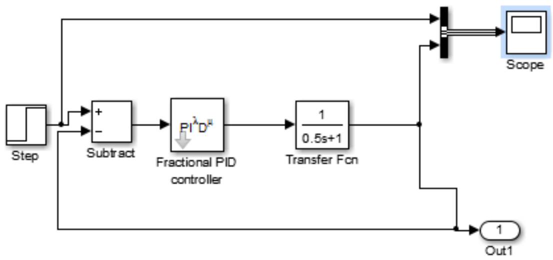

Fig.4 1st order unity feedback system with T=0.5 and FOPID controller

The FOPID controller for above system is shown below:

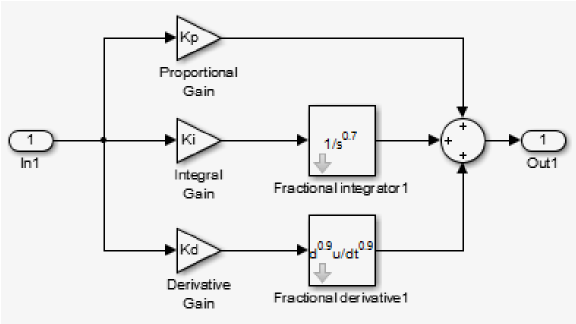

Fig.5 FOPID controller

The results of the above setups in simulink are as under:

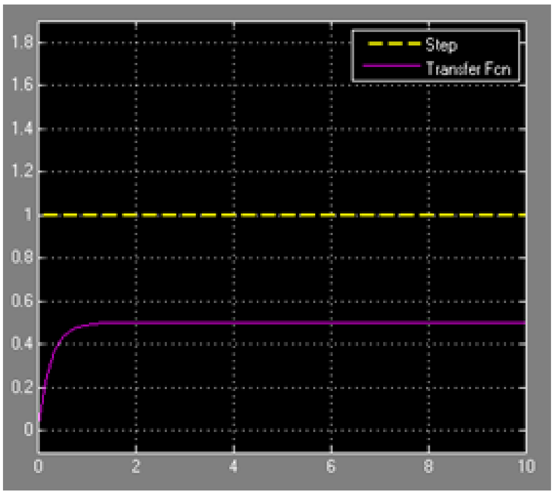

Fig.6 Ouput of 1^{st} order ufb control system

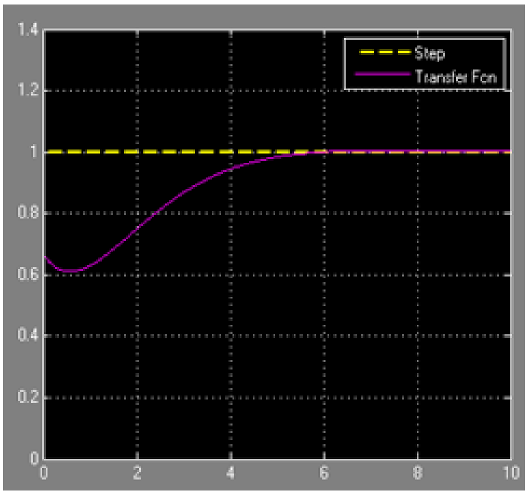

Fig.7 Output of PID controller for 1st order system

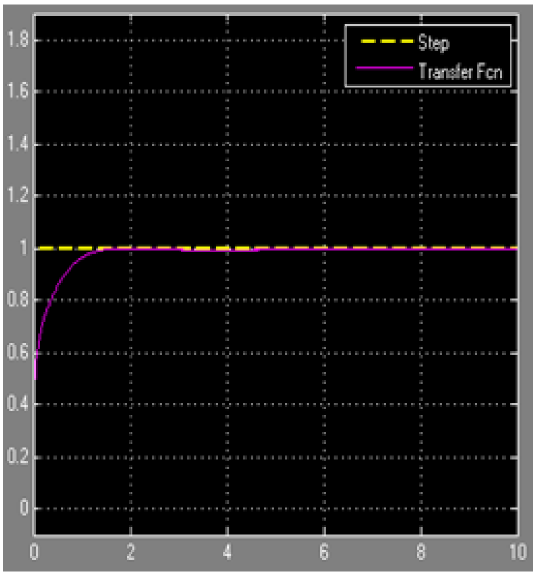

Fig.8 output of FOPID controller for 1st order system

As can be seen from the results, that the best result is obtained from FOPID controller which has less rise time and less settling time as compared to PID controller.

Example 2 higher order control system

$$G(s) = \frac{5}{s^4 + 3s^3 + 7s^2 + 5s}$$

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The designed systems for above G(s) with unity feedback, PID controller with gain settings of Kp=Ki=Kd=2 and FOPID with settings Kp=3,Ki=1.1 Kd=1.5,λ=1and μ=1.1 is shown in fig.9

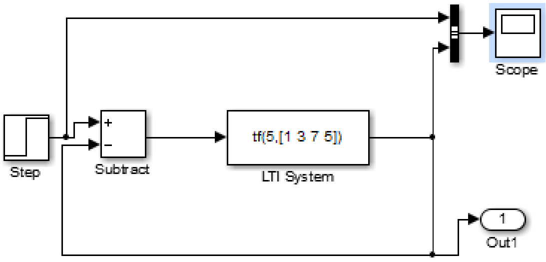

Fig.9 higher order system with unity feedback

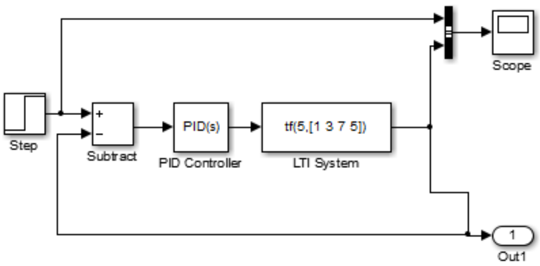

Fig.10 higher order system with ufb and PID controller

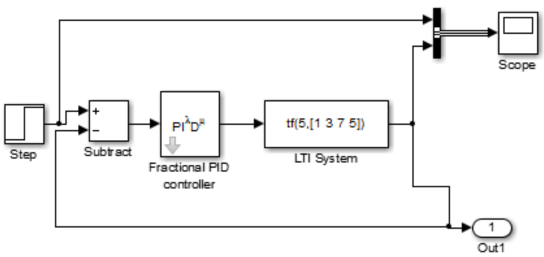

Fig.11 higher order system with ufb and FOPID controller

The FOPID controller for this problem is as in fig.9

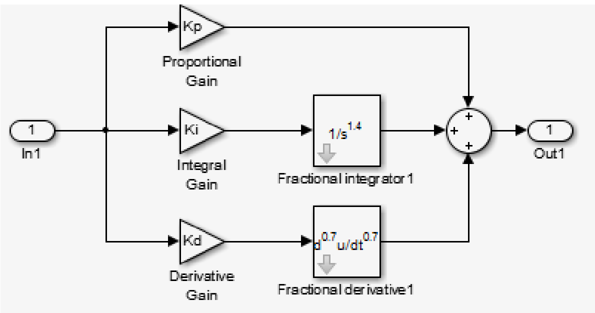

Fig12 FOPID controller for example2

The response of all these above designed systems are shown for unit step input applied:

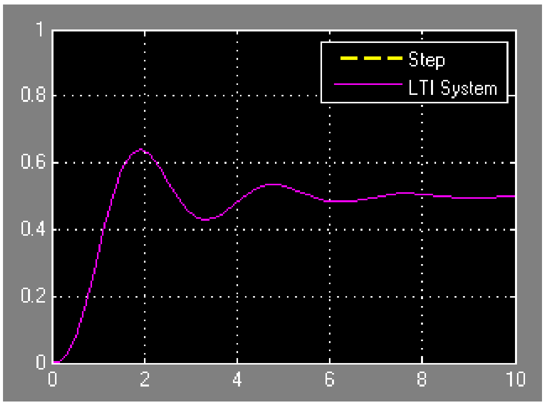

Fig.13 response of 4th order system

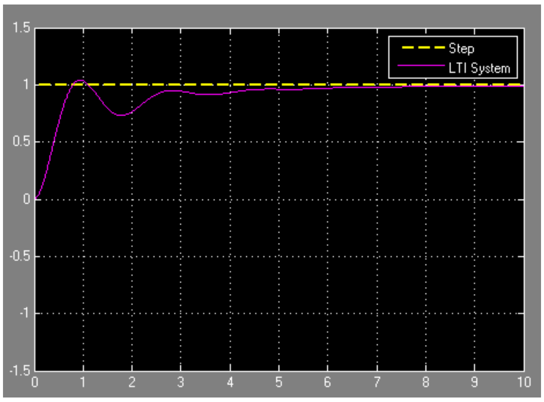

Fig.14 output response of 4th order system with (PID)

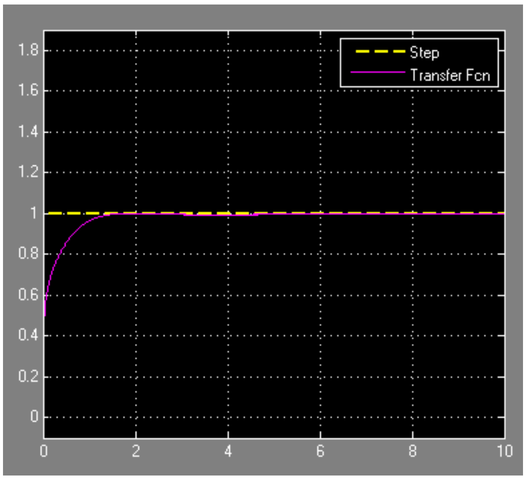

Fig.15 output response of 4th order system with FOPID

As can be seen from the graphs of fig 13,14and 15 that the smoothest and best response is achieved with FOPID controller.

Example 3 inverted pendulum which is an unstable system is considered

$$G(s) = \frac{1}{s^2 - 1}$$

The designed simulink is shown in fig.16 for inverted pendulum with unity feedback and unit step input,fig.17 shows this system when PID is applied with Kp=Ki=Kd=1 and fig.18 with FOPID and gain parameters as Kp=2,Ki=6, Kd=1.1, λ=0.9, μ=0.7

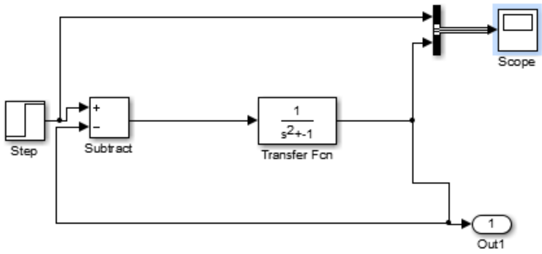

Fig.16 inverted pendulum with unity feedback.

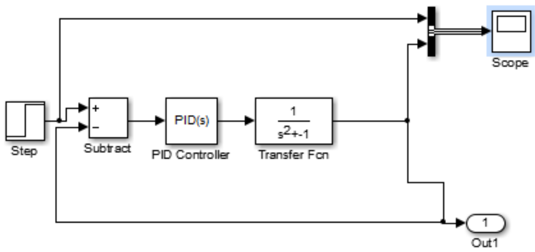

Fig.17 inverted pendulum with PID controller

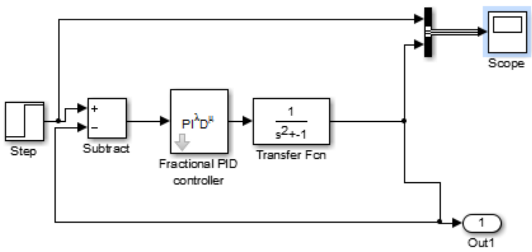

Fig.18 inverted pendulum with FOPID

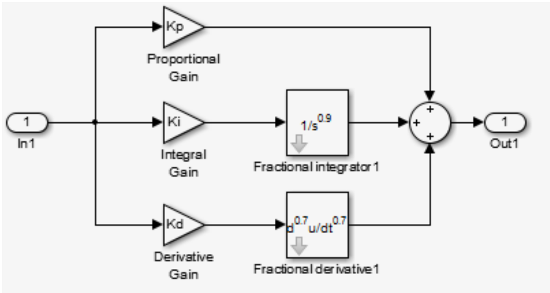

Fig.19 FOPIDcontroller used for the inverted pendulum problem

The results of these controllers are given below:

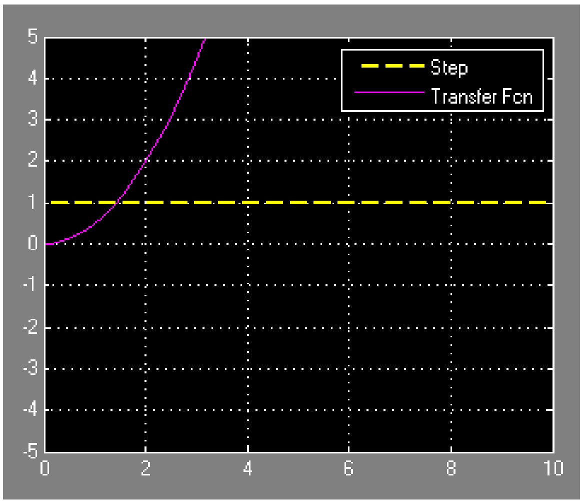

Fig.20 output response of inverted pendulum

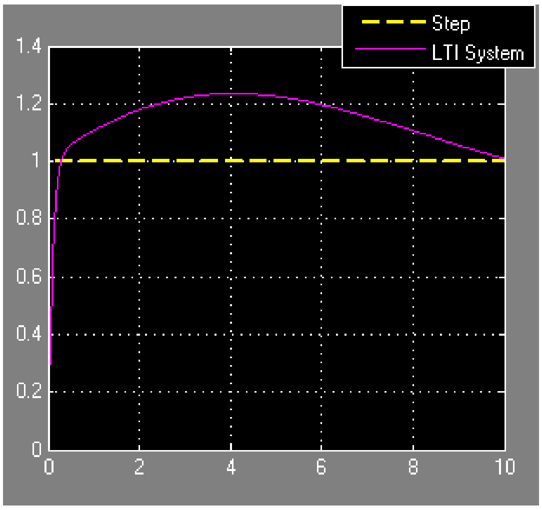

Fig.21 output response of inverted pendulum with PID

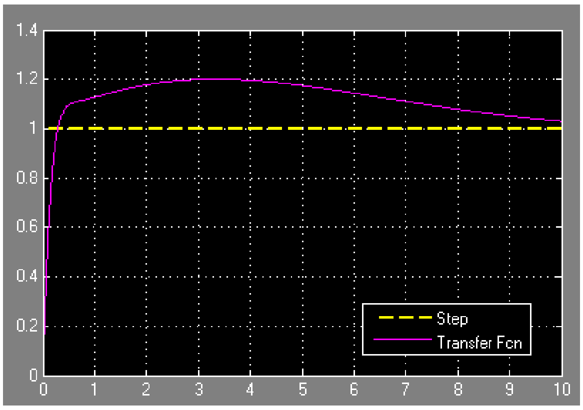

Fig.22 output response of inverted pendulum with FOPID

6. Conclusion

As can be seen from above responses in fig7, fig8, fig14, fig15, fig21 and fig22 for different processes that after implementing FOPID various time domain specifications such as rise time, settling time Mp and Ess gets reduced more as compared to the system responses applied with integer PID controller. So, the responses indicates and verify that FOPID controller outperforms classical PID controller for the above set of processes.

7. Future Work

In future, optimization algorithms, fuzzy technique, time delay processes, and change in structure can be applied to these problems and results can be compared.

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