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FUZZY PROPORTIONAL-DERIVATIVE SLIDING MODE CONTROL WITH MINIMAL RULES FOR DISK READ SYSTEM

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Abstract: In this paper, the position control of frame work(disk-drive system) using proportional-derivative fuzzy sliding mode is proposed. First, the mathematical model of D.C motor and related components of the whole system is derived, model reduction technique is used to simplify the transfer function, then a designed classical controllers, like proportional-derivative(PD), linear quadratic regulator(LQR) are investigated, finally PD-fuzzy sliding mode control is derived with minimal rules for fuzzy is derived to compensate the uncertainties , which occur in the control, in which fuzzy logic control is used to compensate the chattering from applying the sliding mode control. The numerical validation results of the proposed scheme have presented good performance in transient and steady-state behavior (improving settling time and maximum overshoot) compared to the conventional controllers. So sliding mode fuzzy control is superior when compared with other controllers in terms of control performance. Various control schemes are then compared with each other. Simulations are carried out by using MATLAB.

Keywords: *Sliding Mode Control, Fuzzy Control, PID Control, linear quadratic regulator, DC Motor, Matlab/Simulink.*

المسيطر التناسبي التفاضلي مع وضع انزلاق غامض باستخدام قواعد الحد الادنى لمحرك قراءة الاقراص

الخلاصة: في هذا البحث, يتم استخدام السيطرة على حركة الوضع لنظام محرك الأقراص باستخدام مسيطر تناسبي تفاضلي عند وضع انزلاق غامض , حيث أولا يتم اشتقاق نموذج رياضي لمكونات محرك ذو تيار مستمر بعدها يتم اختزاله إلى درجة اقل. تم استخدام مجموعة مسيطرات تقليدية مثل المسيطر التناسبي التفاضلي,كذلك المسيطر الخطي من الدرجة الثانية وأخيرا يتم تعريض المحرك إلى المسيطر المقترح وهو التحكم المنطقي الضبابي مع استخدام وضع الانزلاق مع قواعد الحد الأدنى للمتحكم المنطقي.تم الحصول على نتائج أفضل من حيث سرعة الأداء وكذلك أعلى قمة تذبذب مقارنة مع بقية المسيطرات.تم استخدام المحاكاة بواسطة الماتلاب.

1. Introduction

In this paper, the example of disk drives read system is presented to precisely control the position of reader head in order to read data stored on a track on the disk. This proposed closed-loop system uses a motor to actuate (move) the arm to the

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desired location on the disk [1], when it is dealing with actual system, there is some nonlinearities in flexure spring between motor mass and head mass and this consider difficulty in control. Traditional control system has shown satisfactory performance in controlling linear systems and some cases of nonlinear systems. However, there is still a necessary to develop a more efficient control system for nonlinear systems. There are many classical design methods dealing with such system ,likes proportional integral derivative (PID), lag-lead compensators, pole placement technique (PPT) based controller[2,3,4].

New control techniques, such as fuzzy logic control (FLC) are being a large field of research [5, 6].The preliminary applications of this control shown a promising success. Sliding mode control (SMC) was initially proposed in mid 1950[7]. The variable structure (VS) methodology utilizing (SMC) has been the concentration of many reviews and research for the control. The objective of the (VS) is to oblige the framework direction to the sliding surface through the utilization of the proper exchanging rationale.

The (SMC) can offer great properties, for example, cold-heartedness to parameter varieties, outside unsettling influence dismissal, and quick progression reaction [8]. The fluffy controller is weaker in dependability since it does not have a strict arithmetic model to illustrate. (SMC) can be utilized to be a premise to guarantee the solidness of the controller, yet the element of a smooth control activity of FLC can be utilized to beat the burdens of the SMC frameworks. For the most part the sliding mode control hypothesis utilizes intermittent control activities to drive state directions toward a particular hyper plane until a steady balance state is reached. This principle provides a guidance to design a (FLC).The fuzzy sliding mode control (FSMC) contains both (FLC) and (SMC). It provides a simple way to achieve asymptotic stability of the system. In addition, the (FSMC) includes a minimal fuzzy set of the fuzzy controller and provides systematic design procedure.

In this paper , the performance of (FLC) in controlling linear dynamic system, such as second order system(Disk-drive read) with sliding mode trajectory are mixing together to give the best response. Different controllers design methods are compared with the proposed method.

2. Model Description

The disk drive, which simplified to a rotating inertia in damping environment, is driven by a linear servo system. Fig (1) shows the diagram of disk-drive.

The theoretical open-loop model of the system in transfer function case as in (1) [1]:

$$G(s)=\frac{\theta}{Vc}=\frac{Kt}{s(1+\tau 1s)(1+\tau 2s)}*\frac{Wn^2}{(s^2+2\varsigma Wns+Wn^2)} \qquad (1)$$

The electromechanically plant transfer function is fifth order one by complementary it with a 2nd order resonance block to model the Head Gimbal Assembly (HGA).

Where

(θ) is the head position of the arm and (Vc) is the voltage input to the servomotor system.

$(\tau 1)$ is electrical time constant and $(\tau 2)$ is mechanical time constant.

Typical parameters $(\tau 1, \tau 2, K_t)$ for disk drive system are given from [9], while for a 2nd order resonance block, let the natural undamped frequency $(Wn = 12560\, rad/\sec)$ and damping ratio $(\varsigma = 0.03)$ from [1], so that (1) can be written as in (2) :-

$$G(s) = \frac{\theta}{Vc} = \frac{20000}{s(s+5)(s+1000)} * \frac{157.8*10^6}{(s^2 + 753.6s + 157.8*10^6)} \qquad (2)$$

As seen from (2), the mathematical model is high-order, and this gives some complexity in analysis and design, so that it is important to using a model-order reduction technique, the simple one is taking only the dominant poles near the **origin** point or imaginary axis of s-plane. [10], so that the poles:-

S=-1000 is neglected, and the roots of 2nd part of the open-loop transfer function is:-

$S_{12} = -377 \pm 1.2554\, j$, the real part is very away from the imaginary axis, so that it is non-dominant complex roots and can be neglected. The simplified transfer function as in (3) :-

$$G(s) = \frac{20}{s(s+5)} \qquad (3)$$

Fig. 2 shows the transient response with step input between original and reduction transfer function. it is clear there is no differences.

Disk-drive read system is a typical positioning system, which the overshoot should be kept as minimum as possible, therefore the desired maximum overshoot of the control system is zero, so that the desired design specifications are [9]:-
Maximum overshoot Mp%=0 and settling time (Ts) = 0.25 sec.

Firstly, Fig. 3 shows the transient response of closed-loop system without controller, where

(Mp=12%)

and (Ts=1.31sec),

here the properties of closed loop system are undesirable, because the transient response is very sluggish and there is overshot.

2.Design By Classical Controllers Methods

There are many methods for design controllers using classical approaches as discussed below:-

3.1. *Design By Proportional-Derivative (PD) Controller*

The transfers function of (PD) controller as in (4):

$$Gc(s) = K_p + K_d S \tag{4}$$

Where (Kp) is proportional gain and (kd) derivative gain.

The closed-loop transfer function of the whole system (system+PD controller) is given in (5):

$$G_{c.l}(s) = \frac{20(K_p + K_d S)}{S^2 + (20K_d + 5)S + 20K_p} \tag{5}$$

When equaling the denominator of (5) with the optimum coefficients based on the ITAE criterion for step input [9]

($s^2 + 1.4W_n s + W_n^2$), it can obtained (Kp) and (Kd).Here (ζ =1) because (Mp=0), to calculate (W_n) can use this equation[11]-

$$Ts = \frac{4}{\zeta W_n} \tag{6}$$

By fixing the desired time (Ts=0.25sec), in (6), so that ($W_n = 16 rad/\sec$)and (Kp=12.8), while (Kd=0.87). Fig. 4 shows the transient response of the system with (PD) controller; still the design specifications are not meet, because there is overshoot and speed response is not meet the design specifications.

3.2 *design by linear quadratic regulator (LQR)*

LQR is a well-known method that provides optimally controlled feedback gains to enable the closed-loop stable and high performance design of systems. The state variable equations of the system by using the MATLAB are as in (7):

$$\dot{x}=Ax+Bu \qquad y = Cx \tag{7}$$

Where,

$$A = \begin{vmatrix} 0 & 1 \\ 0 & -5 \end{vmatrix}$$

$$B = \begin{vmatrix} 0 \\ 1 \end{vmatrix}$$

$$C = \begin{vmatrix} 20 & 0 \end{vmatrix}$$

The LQR is a state feedback controller and the optimal (LQR) control law takes the form (8):

$$U(t)= -K\, x(t) \tag{8}$$

Where the gain (K) is row vector K= [k1 K2]. To determine the value of the gain, we must solve the algebraic Riccati equation [8]. The (LQR) controller design is an iterative process, trial and error iteration over the values of weights in the cost is necessary to arrive at satisfactory controller. Typically (LQR) designs are carried out by choosing values for the design weights matrices(R) and (Q). LQR algorithm defines the optimal pole location based on two cost function(R) and (Q). A simple guideline is to choose these matrices to be diagonal. The design procedures can be found in more details in [11]. In this paper, it chooses , Q=C'*C and R=0.1 to get better transient response. So that a lot of efforts have been made to tune LQR controller parameters for better system's performance since its indispensable in industry and very difficult to get an optimal parameters. The transient response with this design, still there is steady state error , so that a prefilter can be used to eliminate this, see Fig. 4, but in this case the Ts=0.676 sec and not satisfied the design requirements.

4. Design By Modern Controllers Methods

There are many methods for design controllers by using modern approaches such as:-

4.1 *Designs By Sliding Mode Control (SMC)*

A Sliding Mode Controller is a Variable Structure Controller. Essentially, incorporates a few distinctive constant capacities that can delineate state to a control surface, and the exchanging among various capacities is controlled by plant express that is spoken to by an exchanging capacity [12]. Sliding mode control (SMC) is essentially a fast exchanging criticism control; a standout amongst the most recognized elements of the SMC is that subsequent to achieving the sliding surface, the framework has heartiness to Parameter instabilities and outside unsettling influences. The plan of SMC comprises of two fundamental strides. Firstly, one can choose a sliding surface that models the wanted shut circle execution. Also, a control law is outlined with the end goal that the framework state direction is constrained toward the sliding surface; however the significant disadvantage in the (SMC) approach is the undesired wonder of gabbing on account of the irregular change of control laws over the sliding surface. Gabbing must be lessened as specified in[13].There are many sliding surfaces[14], subsidiary differential condition, which is characterized as in (9) is utilized as a part of this paper:-

$$S(t) = ce(t) + e^{\cdot} \tag{9}$$

Where (c) is positive constant, (e) is error and ($e^{\cdot}$) is derivative of error.

From the second theorem of Lyapunov, the stability condition can be written as:

$$\frac{1}{2}S^2 \succ 0 \qquad \text{(Positive definite) is a Lyapunov function}$$

In order to meet that condition, the basic control law (U) of (SMC) is chosen as below [15]:-

$$U=K1\tanh(K2*S) \qquad (10)$$

Where K1 and K2 are positive integers.

A proportional derivative sliding mode controller (PDSMC) for the trajectory tracking of a position system is explained in many literatures [16]. The first step in the (PDSMC) is to combine sliding surface(S) with (PD) controller, for position disk-drive read system as in (11):-

$$U= Kc*S+K1\tanh(K2*S) \qquad (11)$$

Where (Kc) is positive constant. A block diagram of this conventional (PDSMC) controller is shown in Fig. 5 after trial and error chosen Kp=1 , Kd=0.328, K1=2.43 and K2=1. Fig. 6 show the transient response of (PDSMC), the maximum overshoot Mp=10% and Ts=0.75sec, still don’t meeting the design specifications.

4.2 *Design by fuzzy logic control (FLC)*

In recent years the fuzzy logic control technique has been used in many applications, by which the controller performance can be improved significantly as compared to conventional methods in presence of model uncertainties [17]. The basic configuration of an FLC, which comprises four principal components:

1) A fuzzification
2) A knowledge base
3) Decision making logic
4) A defuzification

The first step in fuzzy controller design is to know and define the linguistic values for all linguistic variables. Therefore, we need to define the membership functions for the linguistic variables.

The inputs to fuzzy are error (e) and derivative of error (e).The input membership function , the output membership and the rules based are shown in following Fig. 7, 8, 9 respectively , while Fig. 10 shows the block-diagram of PD-fuzzy control(PDFLC), trial and error tuning, the values of Kp=1 and Kd=0.0833 can be chosen. Fig. 11 shows the transient response of (PDFLC), still settling time (Ts=0.6sec)is not meet the design specifications, also there is small (Mp=1%).

4.3 *Proposed method (PDFSMC)*

This strategy utilizes a system of planning PD fluffy controller, which is based upon variable structures strategies. We can utilize the fluffy counterparts to the sliding mode controller of tanh( ) work, this strategy, which ensure the security of every controller. Presently, the (PDFSMC) was utilized; the quantity of standards ought to be decreased. What's more, the framework is steady, the additions (Kp) and (Kd) was found by utilizing (LQR) technique. Fluffy sliding mode controller can be picked in such an approach to get the best framework conduct r22egarding particular criteria.

With the fluffy sliding mode controller, diverse qualities for pick up (K1) and (K2) in equ (10) can be chosen. An expansive control pick up is connected just when the state vector is far from the sliding complex, so framework moves towards the sliding complex quick, yet when the direction of the framework is close to the sliding complex, the control flag will change (diminish) easily. Fig (12) represents the used simulation model in Simulink for (PDFSMC). The simulation results are given in Fig(13).we can see that the settling time and rise time of (PDFSMC) is less than that of (PD),(LQR),(SMC)and (FLC).

The response of all controllers are compared with respect to rise time, settling time, and maximum overshoot and it is tabulated in table 1 below. It is observed that (PDFSMC) gives better performance when compared with others see fig 14.

Table 1. Comparison table between all controllers

Controller Types	Settling time(sec)	Rise time(sec)	Max.overshot %	Steady-state error
PD	0.314	0.0699	13	0
LQR	0.676	0.298	2.15	0 (with prefilter)
PDSMC	0.75	0.4	0	0
PDFLC	0.6	0.35	1	0
PDFSMC	0.2	0.08	0	0

5. Conclusions

In this paper (PDFSMC) with exchanged additions and numerous established controllers have been considered for controlling the position of D.C engine.An examination technique has been contemplated to demonstrate the relative focal points and impediments of every controller. (PD) is reasonable if there is no aggravations in the framework.

The execution of the proposed control strategy (PDFSMC) is contrasted and the other control approaches. The aftereffects of reproduction demonstrates that the execution of the system drive by using the proposed controller has some advantages than that by using a pure (PDSMC), in addition, the control precision of the system by using(PDFSMC) is improved than that of using either pure(PDSMC) or pure (PDFLC).

So proposed controller is a robust controller, and response of system is improved. It is observed that system performance for (PDFSMC) is better when compared with others controllers.

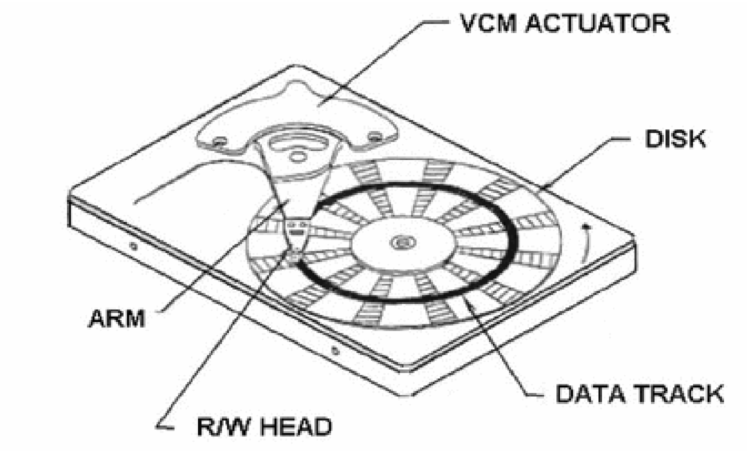


Figure 1. Schematic of a hard disk drive servo system

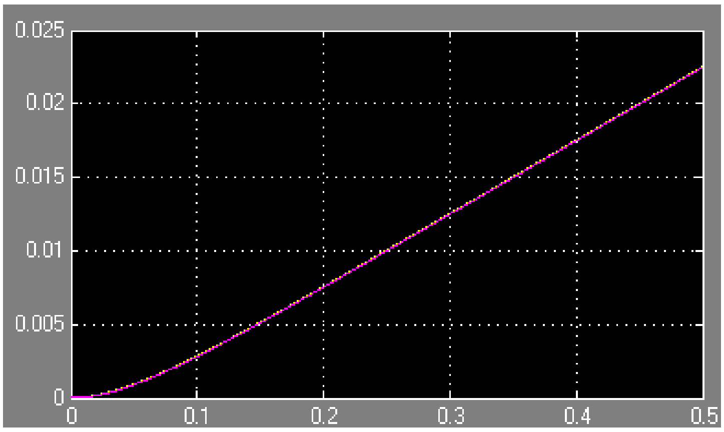


Figure 2. Demonstrates the transient reaction of the original and low-order systems

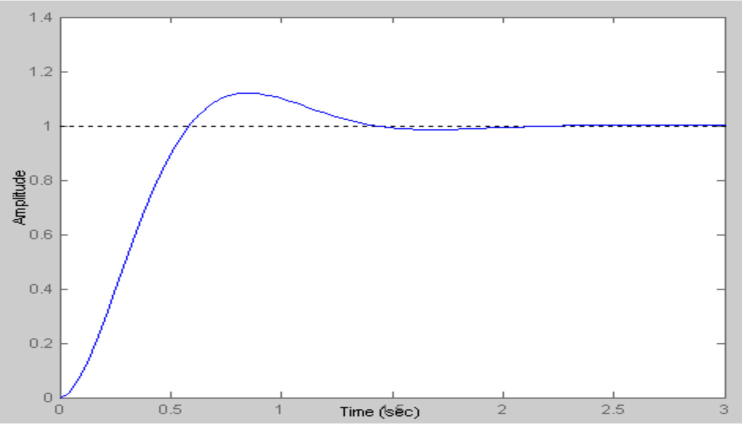


Figure 3. Demonstrates the transient reaction of the framework without controller

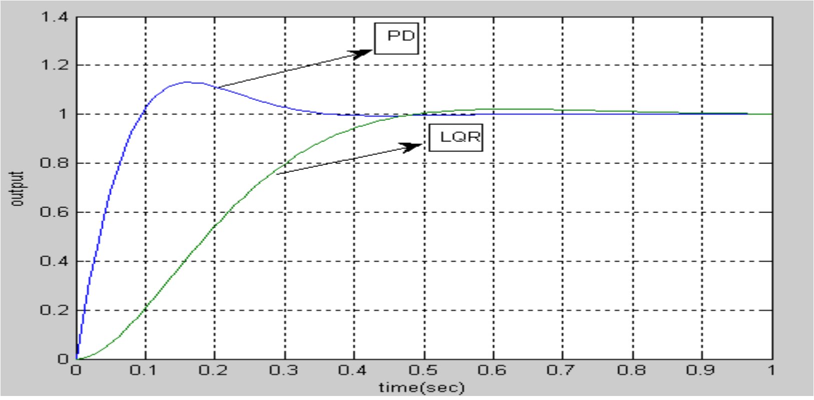


Figure 4. Demonstrates the transient reaction of the framework with (PD) ,(LQR)controller.

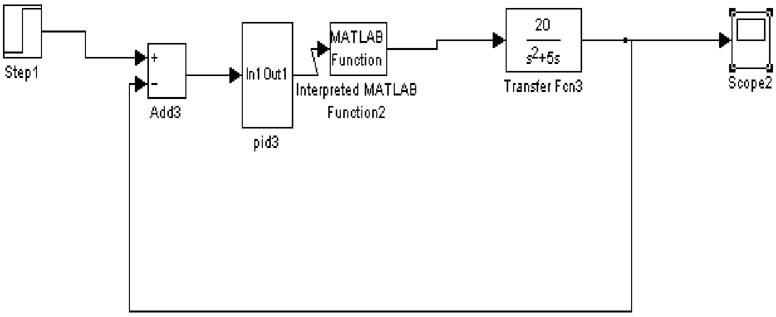


Figure 5. block-diagram of framework with (PDSMC)

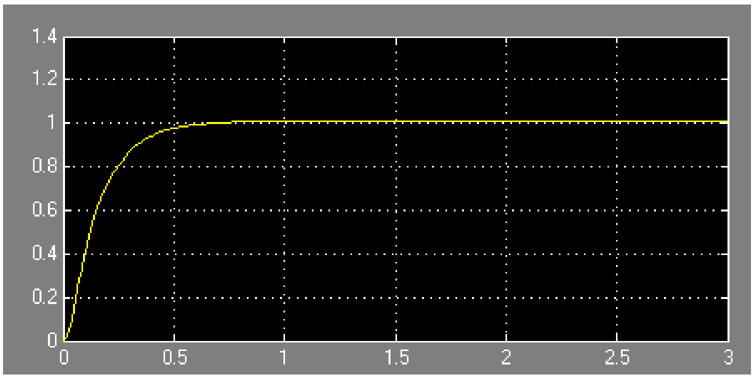


Figure 6. Demonstrates the transient reaction of the framework with (PDSMC)

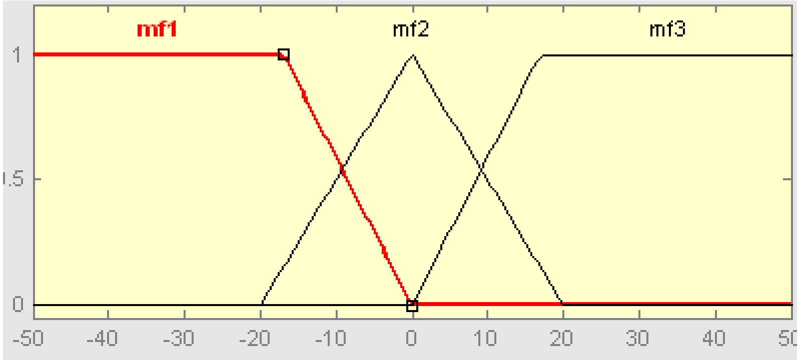


Figure 7. The input membership function for fuzzy control

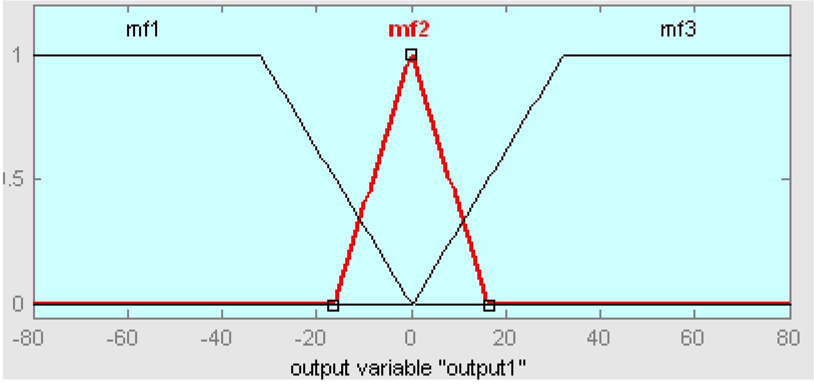
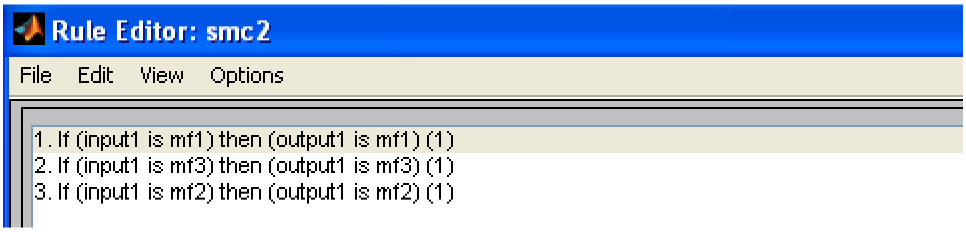


Figure 8. The output membership function for fuzzy control



1. If (input1 is mf1) then (output1 is mf1) (1)
2. If (input1 is mf3) then (output1 is mf3) (1)
3. If (input1 is mf2) then (output1 is mf2) (1)

Figure 9. Rule base for fuzzy controller.

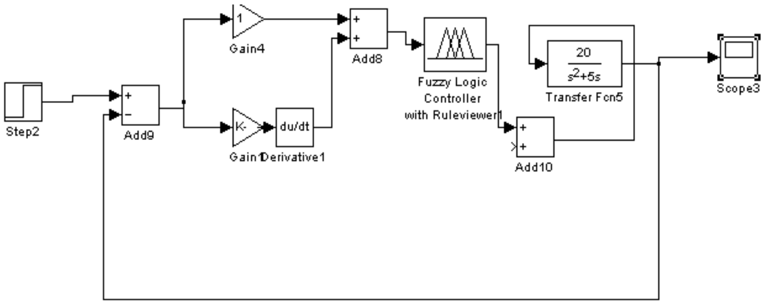


Figure 10. block-diagram of framework with (PDFLC)

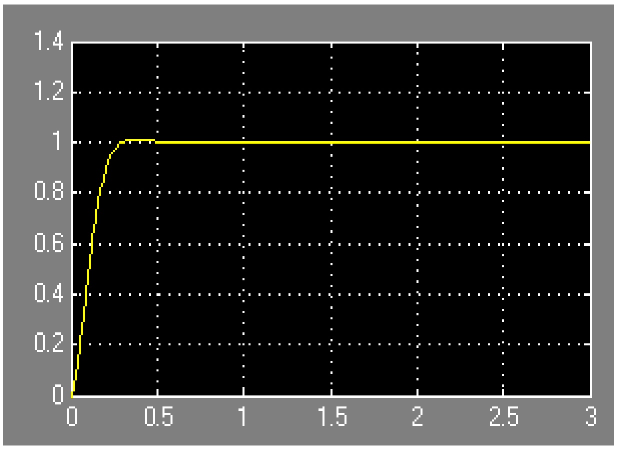


Figure 11. Demonstrates the transient reaction of the framework with (PDFLC)

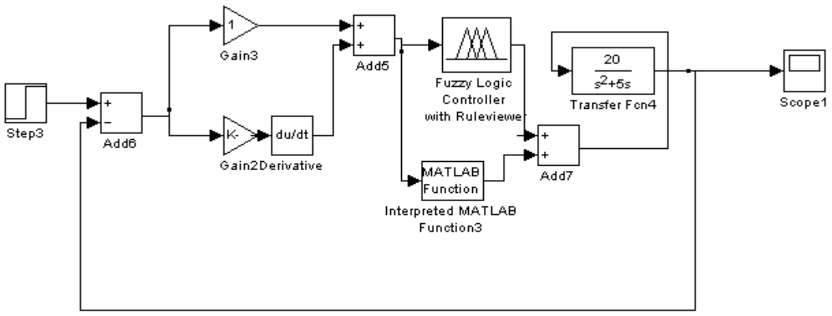


Figure 12. Block diagram of framework with (PDFSMC)

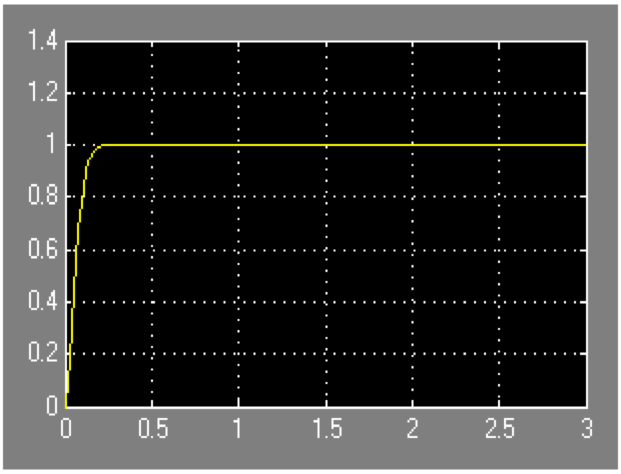


Figure 13. Demonstrates the transient reaction of the framework with (PDFSMC)

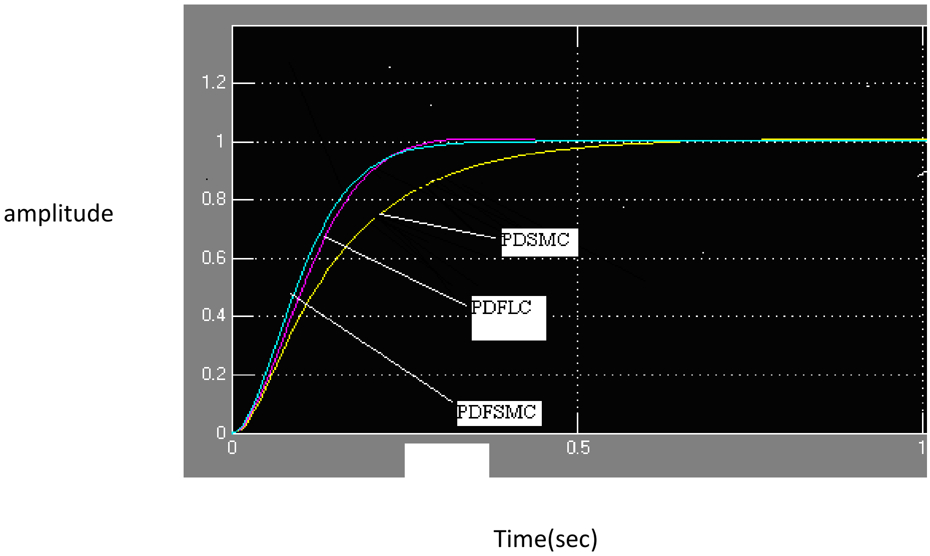


Figure 14. Demonstrates the transient reaction of the framework with different controllers

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