An Adaptive sliding surface slope adjustment in PD Sliding Mode Fuzzy Control for Robot Manipulator

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Abstract

Robotic manipulators are multi-input multi-output (MIMO), nonlinear and most of dynamic parameters are uncertainty so design a high performance controller for these plants is very important. Today, strong mathematical tools used in new control methodologies to design adaptive nonlinear robust controller with acceptable performance. One of the best nonlinear robust controller which can be used in uncertainty nonlinear systems, are sliding mode controller but pure sliding mode controller has some disadvantages such as nonlinear dynamic uncertainties therefore to design model free sliding mode controller this research focuses on applied fuzzy logic controller in sliding mode controller. One of the most important challenging in pure sliding mode controller and sliding mode fuzzy controller is sliding surface slope coefficient therefore the second target in this research is design a supervisory controller to adjusting the sliding surface slope in sliding mode fuzzy controller.

Keywords: *uncertainty parameter, adaptive nonlinear robust controller, sliding mode controller, model free sliding mode controller, fuzzy logic controller, sliding mode fuzzy controller, sliding surface slope.*

1. Introduction

One of the important challenging in control algorithms is design linear behavior controller to easier implementation for nonlinear systems but these algorithms have some limitation such as controller working area must to be near the system operating point which this adjustment is very difficult specially when the dynamic system parameters have large variations and hard nonlinearities [1]. To eliminate above problems in nonlinear physical systems most of control researcher go toward to select nonlinear robust controller.

One of the most important powerful nonlinear robust controllers is sliding mode controller (SMC) [2]. However Sliding mode control methodology was first proposed in the 1950 but this controller has been analyzed by many researchers in recent years. The main reason to select this controller in wide range area is have an acceptable control performance and solve some main challenging topics in control such as resistivity to the external disturbance and uncertainty. However, SMC has many advantages but, pure sliding mode controller has following disadvantages i.e. chattering problem, sensitive, and equivalent dynamic formulation [3].

Fuzzy logic theory was introduced by Dr. Zadeh in 1960 and this method is applied in control science very quickly to design model free nonlinear controller for nonlinear second order systems. This controller can be used to control of nonlinear, uncertain, and noisy systems. However pure FLC works in many engineering applications but, it cannot guarantee stability and acceptable performance [4]. Some researchers applied fuzzy logic methodology in sliding mode controllers (FSMC) and the other researchers applied sliding mode methodology in fuzzy logic controller (SMFC), therefore FSMC is a controller based on SMC but SMFC works based on FLC.

Adaptive control used in systems whose dynamic parameters are varying and/or have unstructured disturbance and need to be training on line. Adaptive fuzzy inference system provide a good knowledge tools for adjust a complex uncertain nonlinear system with changing dynamics to have an acceptable performance. Combined adaptive method to artificial sliding mode controllers can help to controllers to have a better performance by online tuning the nonlinear and time variant parameters [5-8].

This paper is organized as follows:

In section 2, classical sliding mode methodology is presented. Detail of design PD sliding mode fuzzy controller is presented in section 3. In section 4, design mathematical adaptive model-free sliding mode fuzzy controller is presented. In section 5, the application this controller on robot manipulator is presented. In section 6, the simulation result is presented and finally in section 7, the conclusion is presented.

2. Classical Sliding Mode Methodology

Sliding mode controller (SMC) is a powerful nonlinear controller which has been analyzed by many researchers especially in recent years. The sliding mode control law divided into two main parts [1, 9, 15-16];

$$\hat{\tau} = \hat{\tau}_{eq} + \hat{\tau}_{dis} \tag{1}$$

Where, the model-based component $\hat{\tau}_{eq}$ is compensated the nominal dynamics of systems and τ_{dis} is discontinuous part of sliding mode controller and it is computed as

$$\hat{\tau}_{dis} = K.sgn(S) \tag{2}$$

A time-varying sliding surface S is given by the following equation:

$$s(x,t) = (\frac{d}{dt} + \lambda)\ \mathrm{e} = 0 \tag{3}$$

where λ is the constant and it is positive. To further penalize tracking error integral part can be used in sliding surface part as follows:

$$s(x,t) = (\frac{d}{dt} + \lambda)\left(\int_0^t \mathrm{e}\, dt\right) = 0 \tag{4}$$

The main target in this methodology is keep $s(x,t)$ near to the zero when tracking is outside of $s(x,t)$. The function of $sgn(S)$ defined as;

$$sgn(s) = \begin{cases} 1 & s > 0 \\ -1 & s < 0 \\ 0 & s = 0 \end{cases} \tag{5}$$

The K is the positive constant. One of the most important challenges in sliding mode controller based on discontinuous part is chattering phenomenon which can caused to oscillation in output. To reduce or eliminate the chattering it is used the boundary layer method; in boundary layer method the basic idea is replace the discontinuous method by saturation (linear) method with small neighborhood of the switching surface. This replace is caused to increase the error performance.

$$B(t) = \{x, |S(t)| \leq \emptyset\}; \emptyset > 0 \tag{6}$$

Where $\emptyset$ is the boundary layer thickness. Therefore, to have a smote control law, the saturation function $Sat(S/_{\emptyset})$ added to the control law: Suppose that τ_{sat} is computed as

$$\hat{\tau}_{sat} = K.sat\left(S/_{\emptyset}\right) \tag{7}$$

Where $Sat\left(S/_{\emptyset}\right)$ can be defined as

$$sat\left(S/_{\emptyset}\right) = \begin{cases} 1 & (S/_{\emptyset} > 1) \\ -1 & \left(S/_{\emptyset} < 1\right) \\ S/_{\emptyset} & (-1 < S/_{\emptyset} < 1) \end{cases} \tag{8}$$

Moreover by replace the formulation (7) in (1) the control output is written as;

$$\hat{\tau} = \hat{\tau}_{eq} + K.sat\left(S/_{\emptyset}\right) = \begin{cases} \tau_{eq} + K.sgn(S) & ,|S| \geq \emptyset \\ \tau_{eq} + K.S/_{\emptyset} & ,|S| < \emptyset \end{cases} \tag{9}$$

Figure 1 shows the position saturation classical sliding mode control to reduce or eliminate the chattering for robot manipulator.

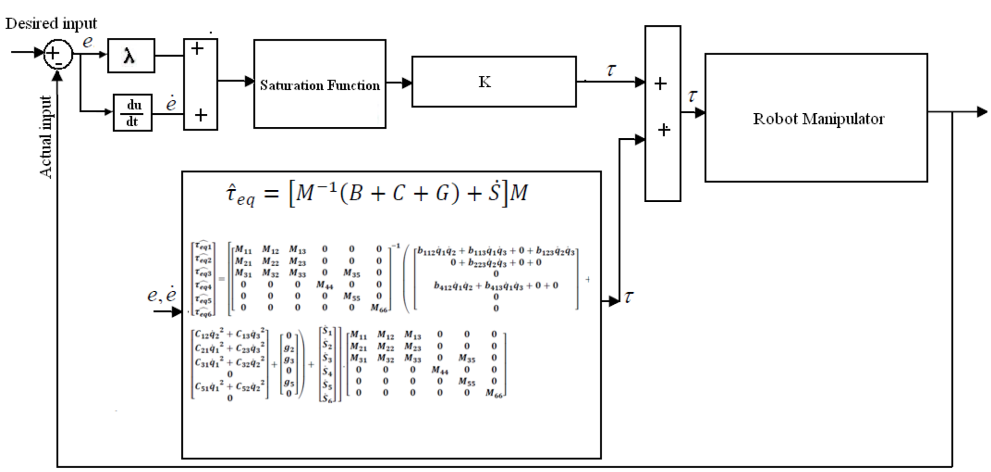

Figure 1 Block diagram of classical sliding mode controller

As shown in Figure 1, sliding mode controller divided into two main parts: equivalent controller, based on dynamics formulation of robot manipulators and sliding surface saturation part based on saturation continuous function to reduce the chattering. Boundary layer method (saturation function) is used to reduce the chattering. Reduce or eliminate the chattering regarding to reduce the error is play important role in this research therefore boundary layer method is used beside the equivalent part to solve the chattering problem besides reduce the error.

3. Design the PD Sliding Mode Fuzzy Controller

A PID fuzzy logic controller (FLC) is a controller which takes error, integral of error and derivative of error as inputs. Fuzzy controller with three inputs is difficult to implementation, because it needs large number of rules, in this state the number of rules increases with an increase the number of inputs or fuzzy membership functions [4-5]. In the PID FLC, if each input has 7 linguistic variables, then $7 \times 7 \times 7 = 343$ rules will be needed. In PD FLC if we have 7 linguistic variables, our controller has $7 \times 7 = 49$ rules. The proposed PD sliding mode fuzzy controller is constructed as a structure of a single sliding surface slope input. This work will reduce the number of rules needed to 7 rules only [10].

The fuzzy part of controller (Figure 2) has one input (S) and one output (τ_{fuzzy}). The input is sliding surface (S) which measures by the equation (3). For simplicity in implementation and also to have an acceptable performance the triangular membership function is used. The linguistic variables for sliding surface (S) are; Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), Positive Big (PB), and it is quantized in to thirteen levels represented by: -6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6 and the linguistic variables to find the output are; Large Left (LL), Medium Left (ML), Small Left (SL), Zero (Z), Small Right (SR), Medium Right (MR), Large Right (LR) and it is quantized in to thirteen levels represented by: -85, -70.8, -56.7, -42.5, -28.3, -14.2, 0, 14.2, 28.3, 42.5, 56.7, 70.8, 85. Design the rule base of fuzzy inference system can play important role to design the best performance of sliding mode fuzzy controller, this paper focuses on heuristic method which, it is based on the behavior of the control systems.

The complete rule base for this controller is shown in Table 1. Rule evaluation focuses on operation in the antecedent of the fuzzy rules in sliding mode fuzzy controller. Max-Min aggregation is used in this work which the calculation is defined as follows;

$$\mu_U(x_k, y_k, U) = \mu_{\bigcup_{i=1}^{r} FR^i}(x_k, y_k, U) = max\left\{min_{i=1}^{r}\left[\mu_{R_{pq}}(x_k, y_k), \mu_{p_m}(U)\right]\right\} \quad \textbf{(10)}$$

The last step to design fuzzy inference in sliding mode fuzzy controller is defuzzification. In this design the Center of gravity method (COG) is used and calculated by the following equation;

$$COG(x_k, y_k) = \frac{\sum_i U_i \sum_{j=1}^{r} \mu_u(x_k, y_k, U_i)}{\sum_i \sum_{j=1}^{r} \mu_u(x_k, y_k, U_i)} \quad \textbf{(11)}$$

Sliding mode fuzzy controller is fuzzy controller based on sliding mode method methodology for easy implementation, improve the stability and robustness [11-12]. In this research (Figure 2) Control rules for SMFC can be described as:

IF S is<ling.var> THEN U is<ling.var> **(12)**

Table 1 is shown the fuzzy rule table for SMFC, respectively:

Table 1. Rule table (SMFC)

S	NB	NM	NS	Z	PS	PM	PB
T	NB	NM	NS	Z	PS	PM	PB

A block diagram for sliding mode fuzzy controller is shown in Figure 2.

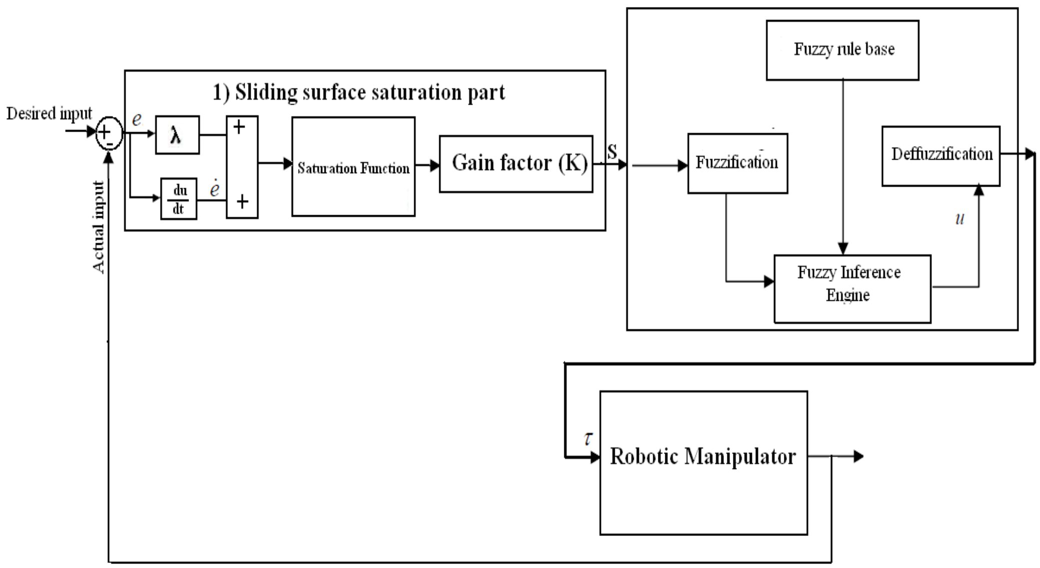

Figure 2. Sliding Mode Fuzzy Control of robot manipulator (SMFC).

It is basic that the system performance is sensitive to the sliding surface slope λ for sliding mode fuzzy controller. For instance, if large value of λ are chosen the response is very fast but the system is very unstable and conversely, if small value of λ considered the response of system is very slow but the system is very stable. Therefore, calculate the optimum value of λ for a system is one of the most important challenging works. SMFC has two most important advantages i.e. the number of rule base is smaller and Increase the robustness and stability.
In this method the control output can be calculated by

$$\tau = \hat{\tau} + \tau_{fuzzy(S)} \quad \textbf{(13)}$$

Where $\hat{\tau}$ the nominal compensation is term and $\tau_{fuzzy(s)}$ is the output of sliding mode fuzzy controller [9].

4. Mathematical Model free Sliding surface slope coefficient adjustment

For nonlinear, uncertain, and time-variant plants (e.g., robot manipulators) adaptive method can be used to self adjusting the sliding surface slope coefficient. Research on adaptive sliding mode fuzzy controller is significantly growing, for instance, the different

ASMFC have been reported in [7, 13-14]. It is a basic fact that the system performance in SMFC is sensitive to sliding surface slope coefficient, λ. Thus, determination of an optimum λ value for a system is an important problem. If the system parameters are unknown or uncertain, the problem becomes more highlighted. This problem may be solved by adjusting the surface slope and boundary layer thickness of the sliding mode controller continuously in real-time. To keep the structure of the controller as simple as possible and to avoid heavy computation, a new supervisor tuner based on updated by a new coefficient factor kn is presented. In this method the supervisor part tunes the output scaling factors using gain online updating factors. The inputs of the supervisor term are error and change of error $(e, \dot{e})$ and the output of this controller is U, which it can be used to tune sliding surface slope, λ.

$$\boldsymbol{k_n = e^2 - \frac{(r_v - r_{vmin})^5}{1 + |e|} + r_{vmin}} \tag{14}$$

$$r_v = \frac{\big(de(k) - de(k-1)\big)}{de(.)} \tag{15}$$

$$de(.) = \begin{Bmatrix} de(k); & if\ de(k) \geq de(k-1) \\ de(k-1) & if\ de(k) < de(k-1) \end{Bmatrix}$$

In this way, the performance of the system is improved with respect to the SMFC controller. So the new coefficient is calculated by;

$$\lambda_{new} = \lambda_{old} \times K_c \tag{16}$$

5. Application

This method is applied to 3 revolute degrees of freedom (DOF) robot manipulator (e.g., first 3 DOF PUMA robot manipulator). The equation of an *n-DOF* robot manipulator governed by the following equation [1, 9]:

$$\boldsymbol{M}(\boldsymbol{q})\ddot{q} + \boldsymbol{N}(\boldsymbol{q}, \dot{q}) = \tau \tag{17}$$

Where $\boldsymbol{\tau}$ is actuation torque, $\boldsymbol{M(q)}$ is a symmetric and positive define inertia matrix, $N(q, \dot{q})$ is the vector of nonlinearity term. This robot manipulator dynamic equation can also be written in a following form:

$$\tau = \boldsymbol{M}(\boldsymbol{q})\ddot{q} + \boldsymbol{B}(\boldsymbol{q})[\dot{q}\ \dot{q}] + \boldsymbol{C}(\boldsymbol{q})[\dot{q}]^2 + \boldsymbol{G}(\boldsymbol{q}) \tag{18}$$

Where the matrix of coriolios torque is $\boldsymbol{B(q)}$, $\boldsymbol{C(q)}$ is the matrix of centrifugal torques, and $\boldsymbol{G(q)}$ is the vector of gravity force. The dynamic terms in equation (15) are only manipulator position. This is a decoupled system with simple second order linear differential dynamics. In other words, the component $\ddot{\boldsymbol{q}}$ influences, with a double integrator relationship, only the joint variable q_i, independently of the motion of the other joints. Therefore, the angular acceleration is found as to be[3]:

$$\ddot{q} = M^{-1}(q).\{\tau - N(q,\dot{q})\} \quad (19)$$

This technique is very attractive from a control point of view. Position control of PUMA-560 robot manipulator is analyzed in this paper; as a result the last three joints are blocked. The dynamic equation of PUMA-560 robot manipulator is given as [15-16];

$$M(\ddot{\theta})\begin{bmatrix}\ddot{\theta}1\\ \ddot{\theta}_2\\ \ddot{\theta}_3\end{bmatrix} + \mathrm{B}(\theta)\begin{bmatrix}\dot{\theta}_1\dot{\theta}_2\\ \dot{\theta}_1\dot{\theta}_3\\ \dot{\theta}_2\dot{\theta}_3\end{bmatrix} + C(\theta)\begin{bmatrix}\dot{\theta}_1^2\\ \dot{\theta}_2^2\\ \dot{\theta}_3^2\end{bmatrix} + G(\theta) = \begin{bmatrix}\tau_1\\ \tau_2\\ \tau_3\end{bmatrix} \quad (20)$$

Where

$$M(q) = \begin{bmatrix} M_{11} & M_{12} & M_{13} & 0 & 0 & 0\\ M_{21} & M_{22} & M_{23} & 0 & 0 & 0\\ M_{31} & M_{32} & M_{33} & 0 & M_{35} & 0\\ 0 & 0 & 0 & M_{44} & 0 & 0\\ 0 & 0 & 0 & 0 & M_{55} & 0\\ 0 & 0 & 0 & 0 & 0 & M_{66}\end{bmatrix} \quad (21)$$

$$B(q) = \begin{bmatrix} b_{112} & b_{113} & 0 & b_{115} & 0 & b_{123} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & b_{214} & 0 & 0 & b_{223} & 0 & b_{225} & 0 & 0 & b_{235} & 0 & 0 & 0 & 0\\ 0 & 0 & b_{314} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ b_{412} & b_{412} & 0 & b_{415} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & b_{514} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\end{bmatrix} \quad (22)$$

$$C(q) = \begin{bmatrix} 0 & C_{12} & C_{13} & 0 & 0 & 0\\ C_{21} & 0 & C_{23} & 0 & 0 & 0\\ C_{31} & C_{32} & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ C_{51} & C_{52} & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\end{bmatrix} \quad (23)$$

$$G(q) = \begin{bmatrix} 0\\ g_2\\ g_3\\ 0\\ g_5\\ 0\end{bmatrix} \quad (24)$$

Suppose $\ddot{q}$ is written as follows

$$\ddot{q} = M^{-1}(q).\{\tau - [B(q)\dot{q}\dot{q} + C(q)\dot{q}^2 + g(q)]\} \quad (25)$$

and H is introduced as

$$H = \{\tau - [B(q)\dot{q}\dot{q} + C(q)\dot{q}^2 + g(q)]\} \tag{26}$$

$\ddot{q}$ can be written as

$$\ddot{q} = M^{-1}(q).H \tag{27}$$

Therefore I for PUMA-560 robot manipulator can be calculated by the following equation

$$H_1 = \tau_1 - [\, b_{112}\dot{q}_1\dot{q}_2 + b_{113}\dot{q}_1\dot{q}_3 + 0 + b_{123}\dot{q}_2\dot{q}_3] - [\, C_{12}\dot{q}_2{}^2 + C_{13}\dot{q}_3{}^2] - g_1 \tag{28}$$

$$H_2 = \tau_2 - [\, b_{223}\dot{q}_2\dot{q}_3] - [\, C_{21}\dot{q}_1{}^2 + C_{23}\dot{q}_3{}^2] - g_2 \tag{29}$$

$$H_3 = \tau_3 - [C_{31}\dot{q}_1{}^2 + C_{32}\dot{q}_2{}^2] - g_3 \tag{30}$$

$$H_4 = \tau_4 - [\, b_{412}\dot{q}_1\dot{q}_2 + b_{413}\dot{q}_1\dot{q}_3] - g_4 \tag{31}$$

$$H_5 = \tau_5 - [\, C_{51}\dot{q}_1{}^2 + C_{52}\dot{q}_2{}^2] - g_5 \tag{32}$$

$$H_6 = \tau_6 \tag{33}$$

6. Results

Pure sliding mode control (SMC), sliding mode fuzzy control (SMFC), and adaptive sliding mode fuzzy control (ASMFC) are implemented in Matlab/Simulink environment. In theses controllers tracking performance and robustness are compared.

Tracking performances: Figures 3, 4 and 5 are shown tracking performance for first, second and third link in SMC, SMFC and AFSMC without disturbance for desired trajectories.

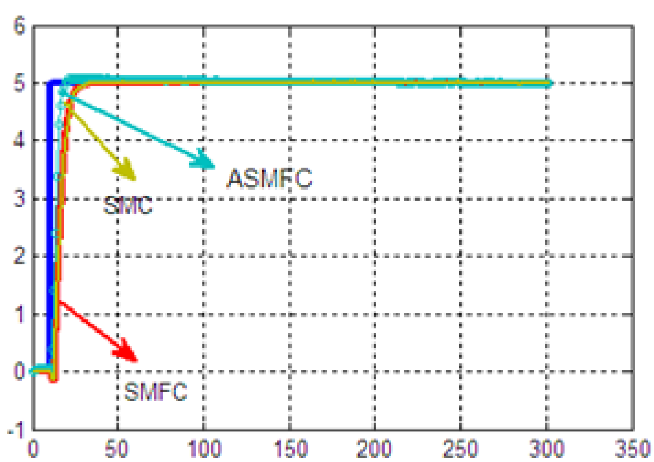

Figure 3. First link trajectory without disturbance

Disturbance rejection: Figures 7, 8 and 9 have shown the power disturbance elimination in SMC, SMFC and ASMFC. The main target in this controller is disturbance rejection as well as the other responses. A band limited white noise with predefined of 40% the power of input signal is applied to the Step SMC, SMFC and ASMFC. It found fairly fluctuations in trajectory responses. As mentioned earlier, SMC works very well when all parameters are known, this challenge plays important role to select the ASMFC as a based robust controller in this research.

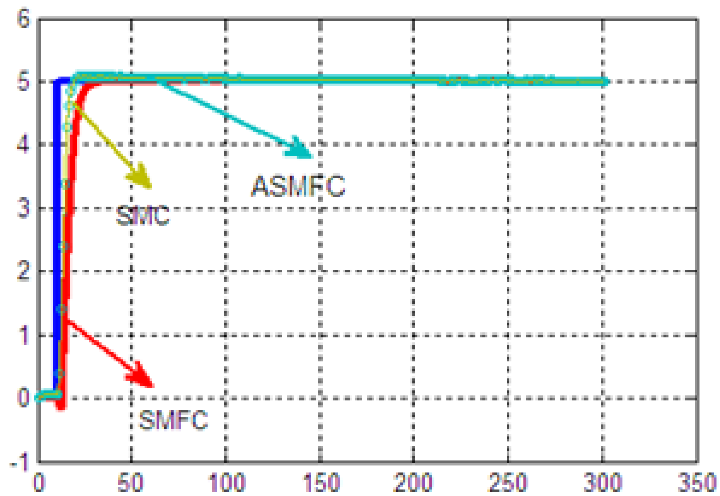

Figure 4. Second link trajectory without disturbance

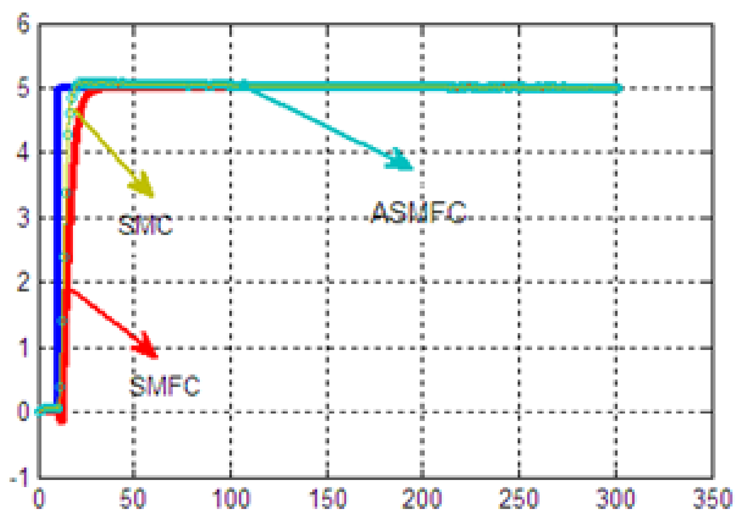

Figure 5. Third link trajectory without disturbance

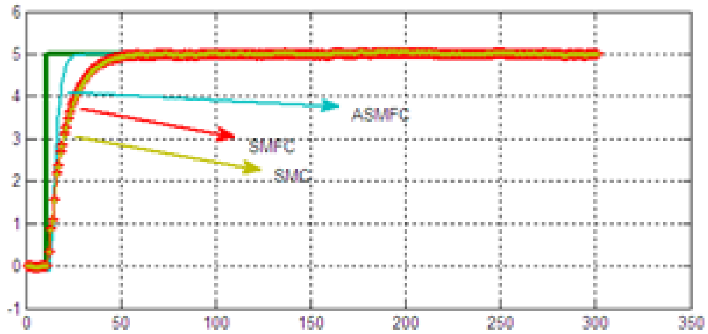

Figure 6. First link trajectory with disturbance

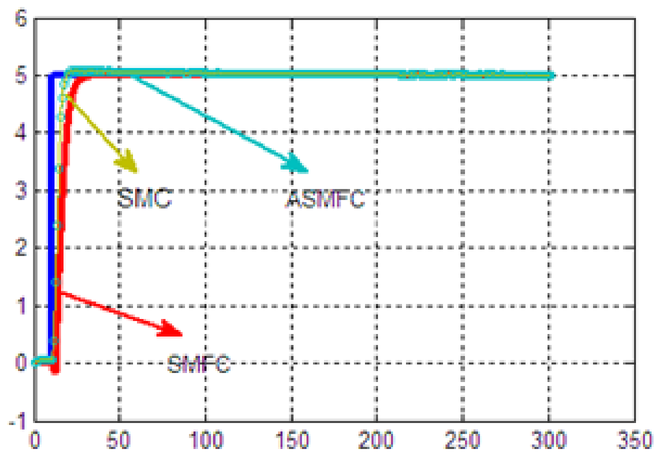

Figure 7. Second link trajectory with disturbance

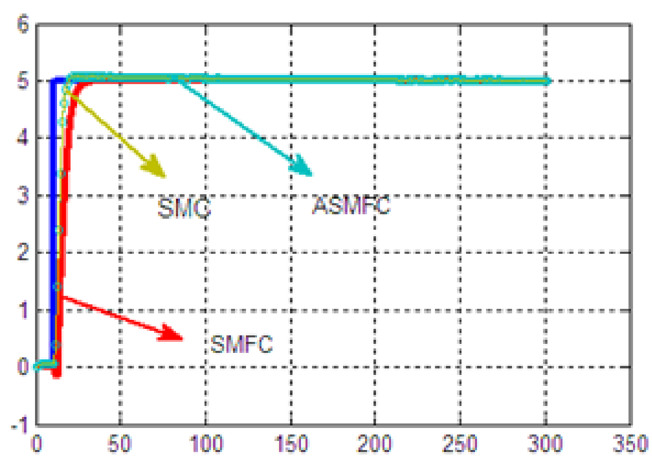

Figure 8. Third link trajectory with disturbance

Among above graphs (6, 7 and 8) relating to Step trajectories following with external disturbance, SMC and SMFC have fairly fluctuations. By comparing some control parameters such as overshoot, rise time, steady state and RMS error it computed that the SMC's and SMFC's overshoot **(1.8%)** is higher than ASMFC's **(1.2%)**, although all of them have about the same rise time; SMC and SMFC **(0.5 sec)** and ASMFC **(0.41 sec)**, the Steady State and RMS error in ASMFC **(Steady State error = -0.0019 and RMS error=0.0025)** is fairly lower than SMC and SMFC **(Steady State error $\cong 0.005$ and RMS error=0.0042)**.

7. Conclusion

Refer to the research, a position adaptive sliding mode fuzzy control (STFSMC) design and application to robot manipulator has proposed in order to design high performance nonlinear controller in the presence of uncertainties. Regarding to the positive points in sliding mode controller, fuzzy logic controller and adaptive method, the response has improved. Each method by adding to the previous method has covered negative points. The main target in this research is analyses and design of the position controller for first three links of PUMA robot manipulator to reach an acceptable performance. In the first part studies about classical sliding mode controller (SMC) which shows that: although this controller has acceptable performance with known dynamic parameters but by comparing the performance regarding to uncertainty, the SMC's output has fairly fluctuations and slight oscillation. Although SMC has many advantages such as stability and robustness but there are two important disadvantages as below: chattering phenomenon and mathematical nonlinear dynamic equivalent controller part. Second step focuses on applied fuzzy logic method in sliding mode controller to solve the stability and robustness in pure fuzzy logic controller. In this part Mamdani's error based controller has considered with one input (**S**) and an output. This controller is independent of nonlinear mathematical dynamic parameters and easier to implement. Controller design is done by using 7 rules Mamdani's fuzzy sliding mode controller, adjusting the expert knowledge's and try and error method. This controller works very well in certain environment but if it works in uncertain area or various dynamic parameters, it has slight chattering phenomenon. The system performance in sliding mode controller and sliding mode fuzzy controller are sensitive to the sliding surface slope. Therefore, compute the optimum value of sliding surface slope for a system is the third important challenge work. This problem has solved by adjusting surface slope of the sliding mode controller continuously in real-time. In this way, the overall system performance has improved with respect to the classical sliding mode controller. By comparing between adaptive sliding mode fuzzy controller and sliding mode fuzzy controller, found that adaptive sliding mode fuzzy controller has steadily stabilised in output response (e.g., torque performance) but sliding mode fuzzy controller has slight chattering in the presence of uncertainties.

References

[1] Slotine J. J. E., and W. Li. Applied nonlinear control, Prentice-Hall Inc, 1991.

[2] Kurfess T. R. Robotics and automation handbook, CRC Press, 2005.

[3] OKYAY KAYNAK. Guest Editorial Special Section on Computationally Intelligent Methodologies and Sliding-Mode Control. IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, 2001, 48(1): 2-3.

[4] L. Reznik, *Fuzzy controllers*: Butterworth-Heinemann, 1997.

[5] S. Mohan and S. Bhanot, 2006."Comparative study of some adaptive fuzzy algorithms for manipulator control," *International Journal of Computational Intelligence,* vol. 3, pp. 303–311.

[6] Wang L. X. Stable adaptive fuzzy control of nonlinear systems. IEEE Trans. Fuzzy systems, 1993, 1(2): 146-154.

[7] Shahnazi R., H. Shanechi, N. Pariz. Position control of induction and servomotors: A novel adaptive fuzzy PI sliding mode control, IEEE Conferences on power engineering, 2006, P.P: 1-9.

[8] Medhaffar H., N. Derbel, and T. Damak. A decoupled fuzzy indirect adaptive sliding mode controller with application to robot manipulator, Int. Journal on modeling, identification and control, 2006, 1(1): 23-29.

[9] Siciliano B, and Khatib O. Handbook of robotics, Springer, 2007.

[10] Emami M. R., Turksen I. B., and Goldenberg A. A. Development of a systematic methodology of fuzzy logic modelling, IEEE Trans. On fuzzy systems, 1998, 6(3):346-361.

[11] Zhang X., and Z. Man. A new fuzzy sliding mode control scheme, 3^{rd} world congress on intelligent control and automation, 2000, P.P: 1692-1696.

[12] Shahnazi R., H. Shanechi, N. Pariz. Position control of induction and servomotors: A novel adaptive fuzzy PI sliding mode control, IEEE Journals on energy conversions, 2008, 23(1): 138-147.

[13] Weng C. C., W. S. Yu. Adaptive fuzzy sliding mode control for linear time-varying uncertain systems, IEEE conference on fuzzy systems, 2008, P.P: 1483-1490.

[14] Yu Z. X, Adaptive sliding mode-like fuzzy logic control for nonlinear systems, Journal of communication and computer, 2009, 6(1): 53-60.

[15] F. Piltan, *et al.*, "Artificial Control of Nonlinear Second Order Systems Based on AFGSMC," *Australian Journal of Basic and Applied Sciences, 2011, 5(6)*, pp. 509-522.

[16] F. Piltan, *et al.*, "DESIGN SLIDING MODE CONTROLLER FOR ROBOT NIPULATOR WITH ARTIFICIAL TUNEABLE GAIN," *Canadian Journal of Pure and Applied Sciences, 5(2)*, 2011, pp. 1573-1579.