Design Artificial Nonlinear Robust Controller Based on CTLC and FSMC With Tunable Gain

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Abstract

One of the most active research areas in the field of robotics is robot manipulators control, because these systems are multi-input multi-output (MIMO), nonlinear, time variant and uncertainty. An artificial non linear robust controller design is major subject in this work. At present, robot manipulators are used in unknown and unstructured situation and caused to provide complicated systems, consequently nonlinear classical controllers are used in artificial intelligence control methodologies to design nonlinear robust controller with satisfactory performance (e.g., minimum error, good trajectory, disturbance rejection). Sliding mode controller (SMC) and computed torque controller (CTC) are the best nonlinear robust controllers which can be used in uncertainty nonlinear. Sliding mode controller has two most important challenges in uncertain systems: chattering phenomenon and nonlinear dynamic equivalent part. Computed torque controller works very well when all nonlinear dynamic parameters are known. This research is focused on the applied non-classical method (e.g., Fuzzy Logic) in robust classical method (e.g., Sliding Mode Controller and computed torque controller) in the presence of uncertainties and external disturbance to reduce the limitations. Applying the Mamdani's error based fuzzy logic controller with minimum rules is the first goal that causes the elimination of the mathematical nonlinear dynamic in SMC and CTC. Second target focuses on the elimination of chattering phenomenon with regard to the variety of uncertainty and external disturbance in fuzzy sliding mode controller and computed torque like controller by optimization the tunable gain. Therefore fuzzy sliding mode controller with tunable gain (GTFSMC) and computed torque like controller with tunable gain (GTCTLC) will be presented in this paper.

Keywords: robot manipulator, nonlinear robust controller, classical controller, minimum error, good trajectory, disturbance rejection, sliding mode controller, computed torque controller, fuzzy sliding mode controller, computed torque like controller and tunable gain.

1. INTRODUCTION

A robot system without any controllers does not to have any benefits, because controller is the main part in this sophisticated system. The main objectives to control robot manipulators are stability and robustness. Many researchers work on designing the controller for robotic manipulators in order to have the best performance. Control of any systems divided in two main groups: linear and nonlinear controller [1].
Most of robot manipulators which work in industry are usually controlled by linear PID controllers. But the robot manipulator dynamic functions are, nonlinear with strong coupling between joints (low gear ratio), structure and unstructured uncertainty, and multi- inputs multi-outputs (MIMO) which, design linear controller is very difficult especially if the velocity and acceleration of robot manipulator be high and also when the ratio between joints gear be small [2]. To eliminate above problems in 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). Sliding mode control methodology was first proposed in the 1950 [3]. This controller has been analyzed by many researchers in recent years. The main reason to opt for this controller is its acceptable control performance wide range and solves some main challenging topics in control such as resistivity to the external disturbance and uncertainty. However pure sliding mode controller has some disadvantages. First, chattering problem can caused the high frequency oscillation of the controllers output [16-23]. Equivalent dynamic formulation is another disadvantage where calculation of equivalent control formulation is difficult since it is depending on the nonlinear dynamic equation [6-11].
Computed torque controller (CTC) is a powerful nonlinear controller which it widely used in control robot manipulator. It is based on Feed-back linearization and computes the required arm torques using the nonlinear Feed-back control law. This controller works very well when all dynamic and physical parameters are known but when the robot manipulator has variation in dynamic parameters, in this situation the controller has no acceptable performance[32-34]. In practice, most of physical systems (e.g., robot manipulators) parameters are unknown or time variant, therefore, computed torque like controller used to compensate dynamic equation of robot manipulator[1,3]. Research on computed torque controller is significantly growing on robot manipulator application which has been reported in [1,3, 32-34].

Some researchers had applied fuzzy logic methodology [4-5] in sliding mode controllers (FSMC) in order to reduce the chattering and to solve the nonlinear dynamic equivalent problems in pure sliding mode controller [6-11, 16-23] and the other researchers applied fuzzy logic methodology in computed torque controller (CTLC) in order to eliminate the nonlinear part in pure computed torque controller. [32-34]

This paper is organized as follows: In section 2, main subject of modelling robot manipulator formulation are presented. This section covers the following details, introducing the dynamic formulation of robot manipulator. In section 3, the main subject of sliding mode controller and formulation are presented. Detail of computed torque controller is presented in section 4. The main subject of designing fuzzy sliding mode controller with tuneable gain and computed torque like controller with tuneable gain are presented in section 5. This section covers the self tuning proposed fuzzy sliding mode controller and self tuning computed torque like controller. This method is used to reduce the chattering and estimate the equivalent (nonlinear) part in both controllers. In section 6, the simulation result is presented and finally in section 7, the conclusion is presented.

2. ROBOTIC MANIPULATOR FORMULATION

Dynamic modelling of robot manipulators is used to describe the behaviour of robot manipulator, design of model based controller, and simulation results. The dynamic modelling describe the relationship between joint motion, velocity, and accelerations to force/torque or current/voltage and also it can be used to describe the particular dynamic effects (e.g., inertia, coriolios, centrifugal, and the other parameters) to behaviour of system. It is well known that the equation of an *n-DOF* robot manipulator governed by the following equation [1,3, 13-15]:

$$\boldsymbol{M(q)\ddot{q} + N(q,\dot{q}) = \tau} \quad \textbf{(1)}$$

Where τ is actuation torque, $\boldsymbol{M(q)}$ is a symmetric and positive define inertia matrix, $\boldsymbol{N(q,\dot{q})}$ is the vector of nonlinearity term. This robot manipulator dynamic equation can also be written in a following form [12, 35]:

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

Where $\boldsymbol{B(q)}$ is the matrix of coriolios torques, $\boldsymbol{C(q)}$ is the matrix of centrifugal torques, and $\boldsymbol{G(q)}$ is the vector of gravity force. The dynamic terms in equation (2) are only manipulator position. This is a decoupled system with simple second order linear differential dynamics. In other words, the component $\ddot{q}$ influences, with a double integrator relationship, only the joint variableq_i, independently of the motion of the other joints. Therefore, the angular acceleration is found as to be [1]:

$$\boldsymbol{\ddot{q} = M^{-1}(q).\{\tau - N(q,\dot{q})\}} \quad \textbf{(3)}$$

3. CLASSICAL SLIDING MODE CONTROLLER

Basically formulation of a sliding mode controller is [3]:

$$\boldsymbol{U = U_{eq} + U_{dis}} \quad \textbf{(4)}$$

Where, the model-based component $\boldsymbol{U_{eq}}$ compensate for the nominal dynamics of the systems. So $\boldsymbol{U_{eq}}$ can be calculated as follows [1, 3]:

$$\boldsymbol{U_{eq} = \left[M^{-1}(B + C + G) + \dot{S}\right]M} \quad \textbf{(5)}$$

Suppose that $\boldsymbol{S = \lambda e + \dot{e}}$ therefore $\boldsymbol{\dot{S} = \lambda\dot{e} + \ddot{q}_d}$.

A simple solution to get the sliding condition when the dynamic parameters have uncertainty is the switching control law:

$$\boldsymbol{U_{dis} = K(\vec{x},t).sgn(s)} \qquad \boldsymbol{sgn(s)} = \begin{cases} \boldsymbol{1} & \boldsymbol{s} > 0 \\ \boldsymbol{-1} & \boldsymbol{s} < 0 \\ \boldsymbol{0} & \boldsymbol{s = 0} \end{cases} \quad \textbf{(6)}$$

Where the $\boldsymbol{K(\vec{x},t)}$ is the positive constant. To reduce chattering many researchers introduced the boundary layer methods, which in this method the basic idea is to replace the discontinuous method by saturation (linear) method with small neighbourhood of the switching surface. Therefore the saturation function $\boldsymbol{Sat}(\boldsymbol{S}/_{\emptyset})$ added to the control law:

$$\boldsymbol{U = K(\vec{x},t).Sat\left(S/_{\emptyset}\right)} \qquad \boldsymbol{sat\left(S/_{\emptyset}\right)} = \begin{cases} \boldsymbol{1} & (\boldsymbol{S}/_{\emptyset} > 1) \\ \boldsymbol{-1} & (\boldsymbol{S}/_{\emptyset} < 1) \\ \boldsymbol{S}/_{\emptyset} & (\boldsymbol{-1} < \boldsymbol{S}/_{\emptyset} < 1) \end{cases} \quad \textbf{(7)}$$

where $\emptyset$ is the width of the boundary layer, therefore the control output can be write as

$$\boldsymbol{U = U_{eq} + K.sat\left(S/_{\emptyset}\right)} = \begin{cases} \boldsymbol{U_{eq} + K.sgn(S)} & , |\boldsymbol{S}| \geq \emptyset \\ \boldsymbol{U_{eq} + K.}\boldsymbol{S}/_{\emptyset} & , |\boldsymbol{S}| < \emptyset \end{cases} \quad \textbf{(8)}$$

Figure 1 shows the block diagram of classical sliding mode controller.

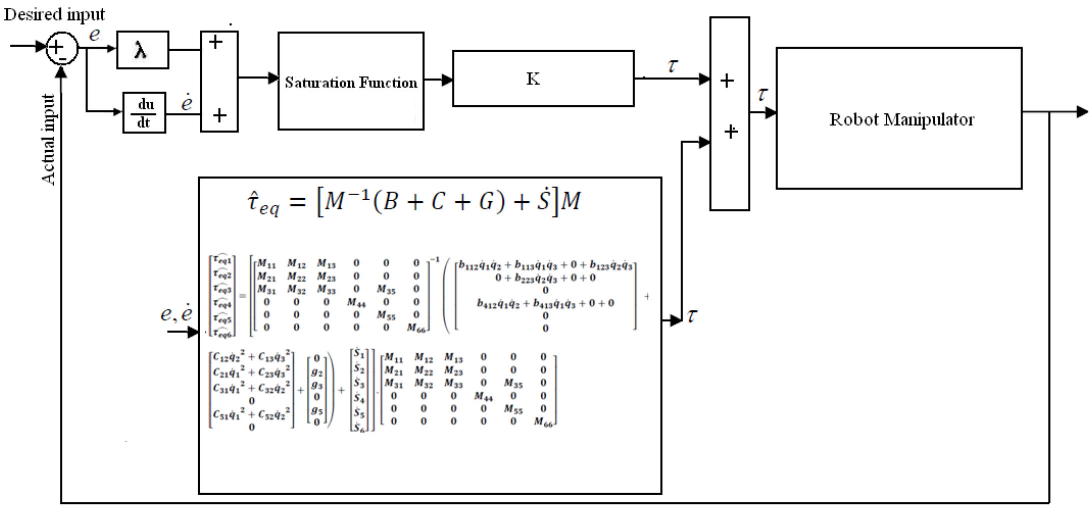

FIGURE 1 : Block diagram of classical sliding mode controller

4. COMPUTED TORQUE CONTROLLER

The central idea of Computed torque controller (CTC) is feedback linearization so, originally this algorithm is called feedback linearization controller. It is assumed that the desired motion trajectory for the manipulator $q_d(t)$, as determined, by a path planner. Define the tracking error as:

$$e(t) = q_d(t) - q_a(t) \quad \textbf{(9)}$$

Where e(t) is error of the plant, $q_d(t)$ is desired input variable, that in our system is desired displacement, $q_a(t)$ is actual displacement. If an alternative linear state-space equation in the form $\dot{x} = Ax + BU$ can be defined as

$$\dot{x} = \begin{bmatrix} 0 & I \\ 0 & 0 \end{bmatrix} x + \begin{bmatrix} 0 \\ I \end{bmatrix} U \quad \textbf{(10)}$$

With $U = -M^{-1}(q).N(q,\dot{q}) + M^{-1}(q).\tau$ and this is known as the Brunousky canonical form. By equation (4) and (5) the Brunousky canonical form can be written in terms of the state $x = [e^T \ \dot{e}^T]^T$ as:

$$\frac{d}{dt}\begin{bmatrix} e \\ \dot{e} \end{bmatrix} = \begin{bmatrix} 0 & I \\ 0 & 0 \end{bmatrix} . \begin{bmatrix} e \\ \dot{e} \end{bmatrix} + \begin{bmatrix} 0 \\ I \end{bmatrix} U \quad \textbf{(11)}$$

$$\text{With } \mathbf{U} = \ddot{\mathbf{q}}_{\mathbf{d}} + \mathbf{M}^{-1}(\mathbf{q}).\{\mathbf{N}(\mathbf{q}.\dot{\mathbf{q}}) - \boldsymbol{\tau}\} \quad \textbf{(12)}$$

Then compute the required arm torques using inverse of equation (12), namely, [1, 3, 6, 12]

$$\tau = M(q)(\ddot{q_d} - U) + N(\dot{q}, q) \quad \textbf{(13)}$$

This is a nonlinear feedback control law that guarantees tracking of desired trajectory. Selecting proportional-plus-derivative (PD) feedback for U(t) results in the PD-computed torque controller[3];

$$\tau = M(q)(\ddot{q}_d + K_v\dot{e} + K_pe) + N(q,\dot{q}) \quad \textbf{(14)}$$

and the resulting linear error dynamics are

$$(\ddot{q}_d + K_v\dot{e} + K_pe) = 0 \quad \textbf{(15)}$$

According to linear system theory, convergence of the tracking error to zero is guaranteed [2].

Where K_p and K_v are the controller gains.
The resulting schemes is shown in Figure 2, in which two feedback loops, namely, inner loop and outer loop, which an inner loop is a compensate loop and an outer loop is a tracking error loop. However, mostly parameter $N(q,\dot{q})$ is all unknown. So the control cannot be implementation because non linear parameters cannot be determined. In the following section computed torque like controller will be introduced to overcome the problems.

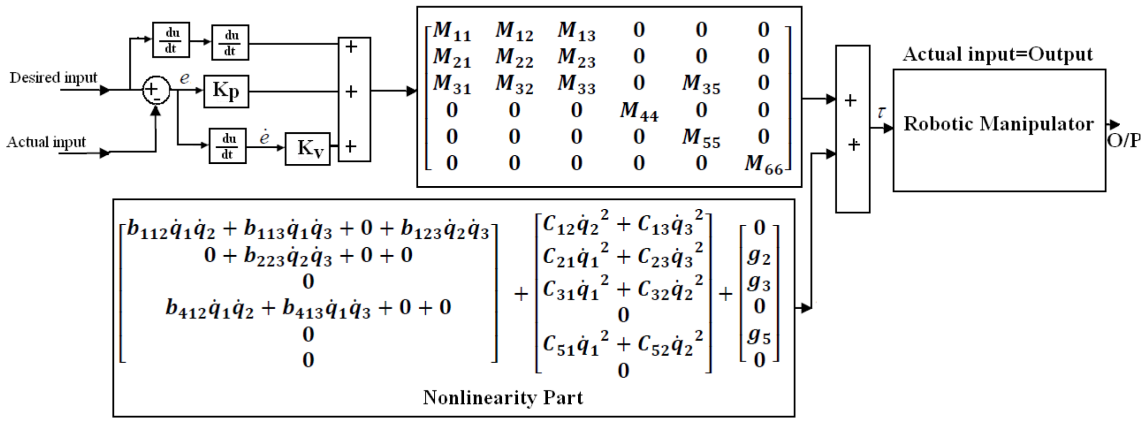

FIGURE 2 : Block diagram of PD-computed torque controller (PD-CTC)

5. FUZZY LOGIC AND ITS APPLICATION TO SLIDING MODE CONTROLLER (FSMC) AND COMPUTED TORQUE CONTROLLER (CTLC)

To compensate the nonlinearity for dynamic equivalent control several researchers used model base fuzzy controller instead of classical equivalent controller that was employed to obtain the desired control behaviour and a fuzzy switching control was applied to reinforce system performance. In the proposed fuzzy sliding mode control fuzzy rule base was designed to estimate the dynamic equivalent part [24-31]. A block diagram for proposed fuzzy sliding mode controller is shown in Figure 3. In this method fuzzy rule for sliding surface (S) to design fuzzy error base-like equivalent control was obtained the rules where used instead of nonlinear dynamic equation of equivalent control to reduce the chattering and also to eliminate the nonlinear formulation of dynamic equivalent control term.

$$\mathbf{1} > if\ S\ is\ NB\ then\ \ \tau\ \ is\ NB \tag{16}$$
$$\mathbf{2} > if\ S\ is\ Z\ then\ \tau\ is\ Z$$

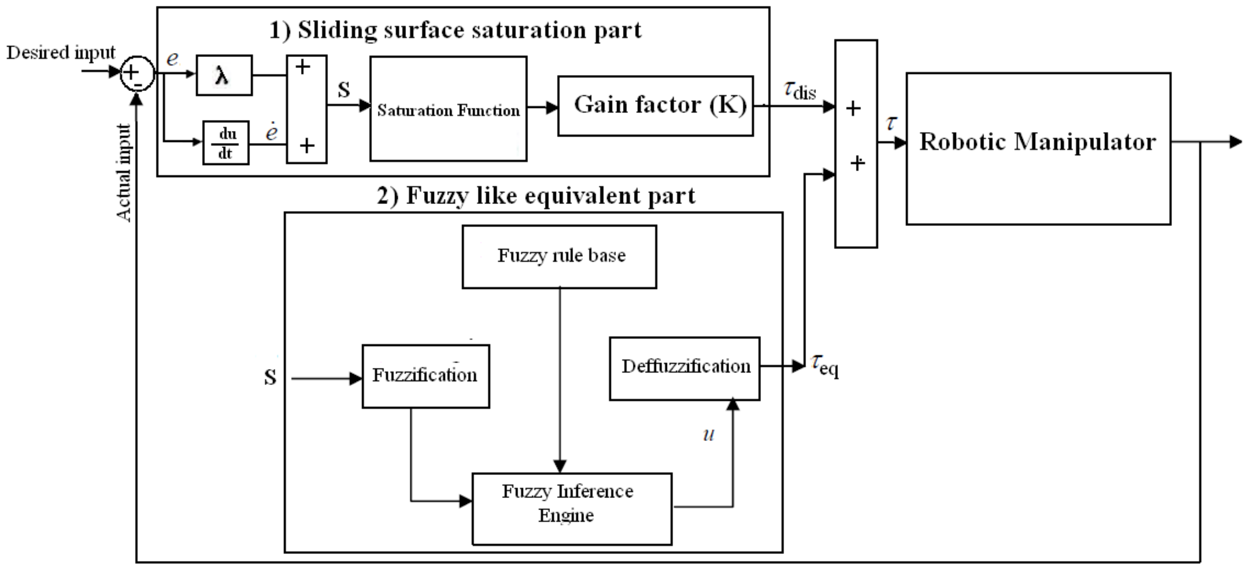

FIGURE 3 : Block diagram of proposed FSMC with minimum rule base

In FSMC the tracking error is defined as:

$$e = q_d - q_a \quad \textbf{(17)}$$

where $q_d = [q_{1d}, q_{2d}, q_{3d}]^T$ is desired output and $q_a = [q_{1a}, q_{2a}, q_{3a}]^T$ is an actual output. The sliding surface is defined as follows:

$$S = \dot{e} + \lambda e \quad \textbf{(18)}$$

where $\lambda = diag[\lambda_1, \lambda_2, \lambda_3]$ is chosen as the bandwidth of the robot manipulator controller. The time derivative of S can be calculated by the following equation

$$\dot{S} = \ddot{q}_d + \lambda_1 \dot{e} \quad \textbf{(19)}$$

Based on classical SMC the FSMC can be calculated as

$$\hat{\tau} = \tau_{fuzzy} + \tau_{sat} \quad \textbf{(20)}$$

Where, the model-based component $\hat{\tau}_{eq}$ compensate for the nominal dynamics of systems. So $\hat{\tau}_{eq}$ can be calculated as

$$\tau_{fuzzy} = \left[M^{-1}(B + C + G) + \dot{S}\right]M \quad \textbf{(21)}$$

and τ_{sat} is

$$\tau_{sat} = K.sat(S) \quad \textbf{(22)}$$

As a summary the design of fuzzy logic controller for FSMC has five steps:

1. **Determine inputs and outputs:** This controller has one input (S) and one output (τ_{fuzzy}). The input is sliding surface (S) and the output is torque(τ_{fuzzy}).
2. **Find membership function and linguistic variable:** 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 into thirteen levels represented by: -1, -0.83, -0.66, -0.5, -0.33, -0.16, 0, 0.16, 0.33, 0.5, 0.66, 0.83, 1, and the

linguistic variables to find the torque (τ_{fuzzy}) 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.

3. **Choice of shape of membership function:** In this work triangular membership function was selected as shown in Figure 4.
4. **Design fuzzy rule table:** design the rule base of fuzzy logic controller can play important role to design best performance SMFC, suppose that two fuzzy rules in this controller are

F.R^1: *IF S is Z, THEN τ is Z.* **(23)**
F.R^2: *IF e is (PB) THEN τ is (LR).*

The complete rule base for this controller is shown in Table 1.

S	NB	NM	NS	Z	PS	PM	PB
τ	LL	ML	SL	Z	SR	MR	LR

TABLE 1: Rule table for proposed FSMC

The control strategy that deduced by table.1 are

- If sliding surface (S) is N.B, the control applied is N.B for moving S to S=0.
- If sliding surface (S) is Z, the control applied is Z for moving S to S=0.

5. **Defuzzification**: The final step to design fuzzy logic controller is deffuzification , there are many deffuzzification methods in the literature, in this controller the COG method will be used, where this is given by

$$COG(x_k, y_k) = \frac{\sum_i U_i \sum_{j=1}^{r} \cdot \mu_u(x_k, y_k, U_i)}{\sum_i \sum_{j=1}^{r} \cdot \mu_u(x_k, y_k, U_i)} \tag{24}$$

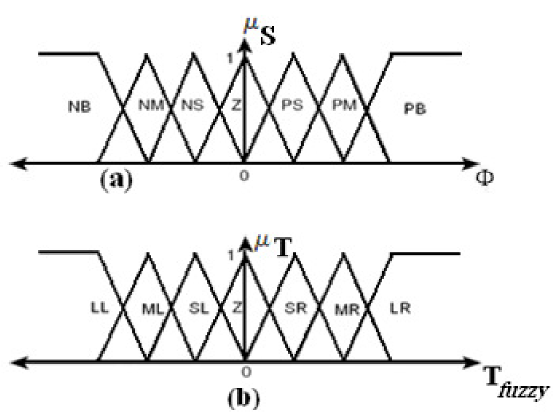

FIGURE 4 : Membership function: a) sliding surface b) torque

As mention previously, computed torque like controller (CTLC) is fuzzy controller based on computed torque method for easy implementation, stability, and robustness. The main drawback of CTLC is the value of gain updating factor K_p *and* K_v must be pri-defined very carefully and the most important advantage of

CTLC compare to pure CTC is a nonlinearity dynamic parameter. It is basic that the system performance is sensitive to the gain updating factors for both computed torque controller and computed torque like controller application. For instance, if large value of K_V is chosen the response is very fast but the system is very unstable and conversely, if small value of K_V considered the response of system is very slow but the system is very stable. Therefore, calculate the optimum value of gain updating factors for a system is one of the most important challenging works. However most of time the control performance for FLC and CTLC is similar to each other, but CTLC has two most important advantages:
The number of rule base is smaller
Increase the robustness and stability
In this method the control output can be calculated by

$$\boldsymbol{\tau} = \hat{\boldsymbol{\tau}} + \boldsymbol{\tau}_{\mathbf{fuzzy}(S)} \qquad \textbf{(25)}$$

Where $\hat{\tau}$ the nominal compensation is term and $\tau_{fuzzy(s)}$ is the output of computed torque fuzzy controller.

The most important target in computed torque like controller (CTLC) is design computed torque control combined to fuzzy logic systems to solve the problems in classical computed torque controller. To compensate the nonlinearity of nonlinear dynamic part several researchers used model base fuzzy controller instead of classical nonlinear dynamic part that was employed to obtain the desired control behaviour and a fuzzy switching control was applied to reinforce system performance. In proposed fuzzy computed torque controller the author design fuzzy rule base to estimate the dynamic nonlinear part. A block diagram for proposed fuzzy computed controller is shown in Figure 5.

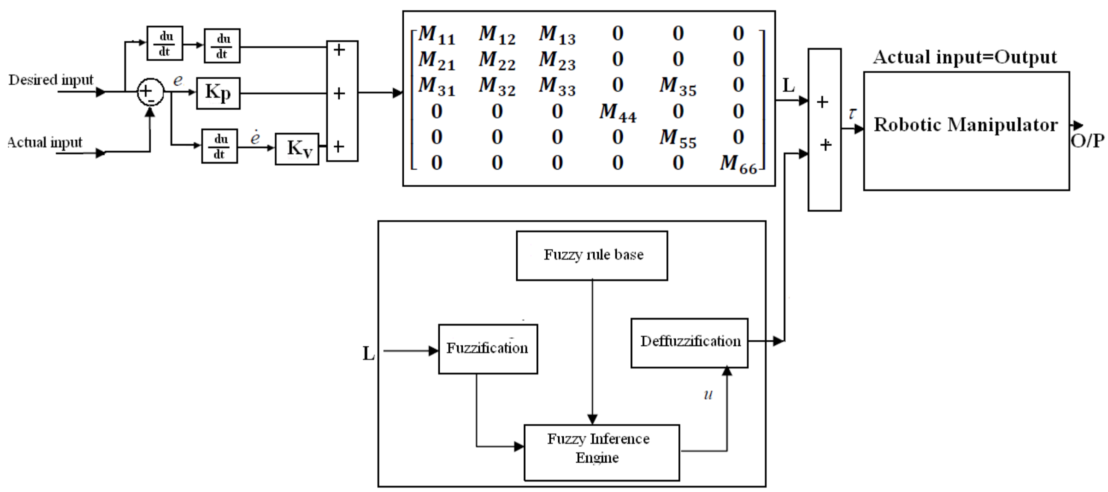

FIGURE 5 : Block diagram of proposed fuzzy computed torque controller with minimum rule base

The sliding surface is defined as follows:

$$\boldsymbol{L} = \boldsymbol{M}(\boldsymbol{q})\left(\ddot{\boldsymbol{q}}_{\boldsymbol{d}} + \boldsymbol{K}_{\boldsymbol{v}}\dot{\boldsymbol{e}} + \boldsymbol{K}_{\boldsymbol{p}}\boldsymbol{e}\right) \qquad \textbf{(26)}$$

Based on classical computed torque controller for a multi DOF robot manipulator:

$$\hat{\boldsymbol{\tau}} = \hat{\boldsymbol{\tau}}_{\boldsymbol{nonlinear}} + \boldsymbol{\tau}_{\boldsymbol{lin}} \qquad \textbf{(27)}$$

where, the model-based component $\hat{\tau}_{nonlinear}$ compensate for the nominal dynamics of systems. So $\hat{\tau}_{nonlinear}$ can calculate as follows:

$$\hat{\boldsymbol{\tau}}_{\boldsymbol{nonlinear}} = \boldsymbol{B}(\boldsymbol{q})\dot{\boldsymbol{q}}\dot{\boldsymbol{q}} + \boldsymbol{C}(\boldsymbol{q})\dot{\boldsymbol{q}}^2 + \boldsymbol{g}(\boldsymbol{q}) \qquad \textbf{(28)}$$

and $\boldsymbol{\tau}_{\boldsymbol{lin}}$ can calculate as follows:

$$\tau_{lin} = M(q)\left(\ddot{q}_d + K_v\dot{e} + K_p e\right) \quad \textbf{(29)}$$

In proposed FSMC nonlinear control part replaced by Mamdani's fuzzy inference term, therefore (27) can be rewrite as the following equation

$$\hat{\tau} = \tau_{fuzzy} + \tau_{lin} \quad \textbf{(30)}$$

6. GAIN TUNING FUZZY SLIDING MODE CONTROLLER (GTFSMC) AND GAIN TUNING COMPUTED TORQUE LIKE CONTROLLER (GTCTLC)

This section focuses on, self tuning gain updating factor for most important factor in FSMC, namely, sliding surface slope (λ) and in self tuning computed torque controller (GTCTLC) namely, nonlinear equivalent part (nonlinear term of controller). The block diagram for this method is shown in Figure 6. In this controller the actual sliding surface gain (λ) is obtained by multiplying the sliding surface with gain updating factor(α). The gain updating factor(α) is calculated on-line by fuzzy dynamic model independent which has sliding surface (S) as its inputs. The gain updating factor is independent of any dynamic model of robotic manipulator parameters.

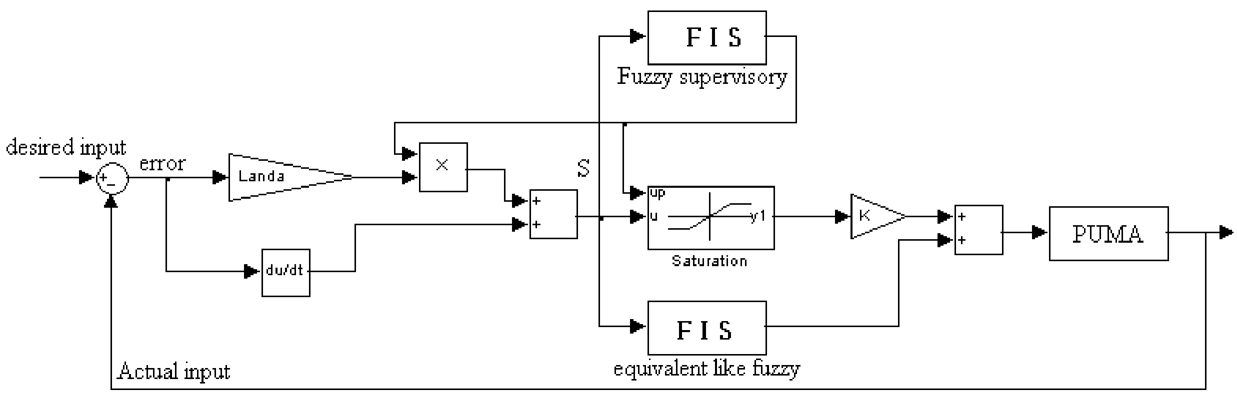

FIGURE 6 : Block diagram of proposed gain tuning fuzzy sliding mode controller with minimum rule base in fuzzy equivalent part and fuzzy supervisory.

proportional and derivative gain updating factor of the computed torque controller continuously in real-time. In this way, the performance of the overall system is improved with respect to the classical computed torque controller. Therefore this section focuses on, self tuning gain updating factor for two type most important factor in CTLC, namely, proportional gain updating factor (K_P) and derivative gain updating factor (K_v). Gain tuning-CTLC has strong resistance and solves the uncertainty problems. The block diagram for this method is shown in Figure 7.

In this controller the actual gain updating factor (K_{new}) is obtained by multiplying the old gain updating factor (K_{old}) with the output of supervisory fuzzy controller(α). The output of fuzzy supervisory controller (α) is calculated on-line by fuzzy dynamic model independent which has sliding surface (S) as inputs.. The value of α is not longer than 1 but it calculated on-line from its rule base. The scale factor, Kv and Kp are updated by equations (18) and (19),

$$K_v^{\,new} = K_v^{\,old} \times \alpha \quad \textbf{(31)}$$

$$K_p^{\,new} = K_p^{\,old} \times \alpha \quad \textbf{(32)}$$

6. Simulation Result

Computed torque controller (CTC), classical sliding mode control (SMC), fuzzy sliding mode control (FSMC), gain tuning computed torque like controller (GTCTLC) and gain tuning fuzzy sliding mode controller (GTFSMC) are implemented in Matlab/Simulink environment for 3 DOF robot manipulator. Tracking performance, error, and robustness are compared.

Tracking performances: Figure 8, 9 and 10 shows tracking performance for first, second and third link of robot manipulator with above controllers. By comparing step response trajectory without disturbance in above controllers, it is found that the GTCLC and GTFSMC overshoot **(1.32%)** are lower than CTC and SMC **(6.44%)**, all of them have about the same rise time. Besides the Steady State and RMS error in GTCTLC and GTFSMC **(Steady State error =0 and RMS error=0)** are fairly lower than CTC and SMC **(Steady State error** $\cong -3^{-5}$ **and RMS error=**-1.6×10^{-5}**)**.

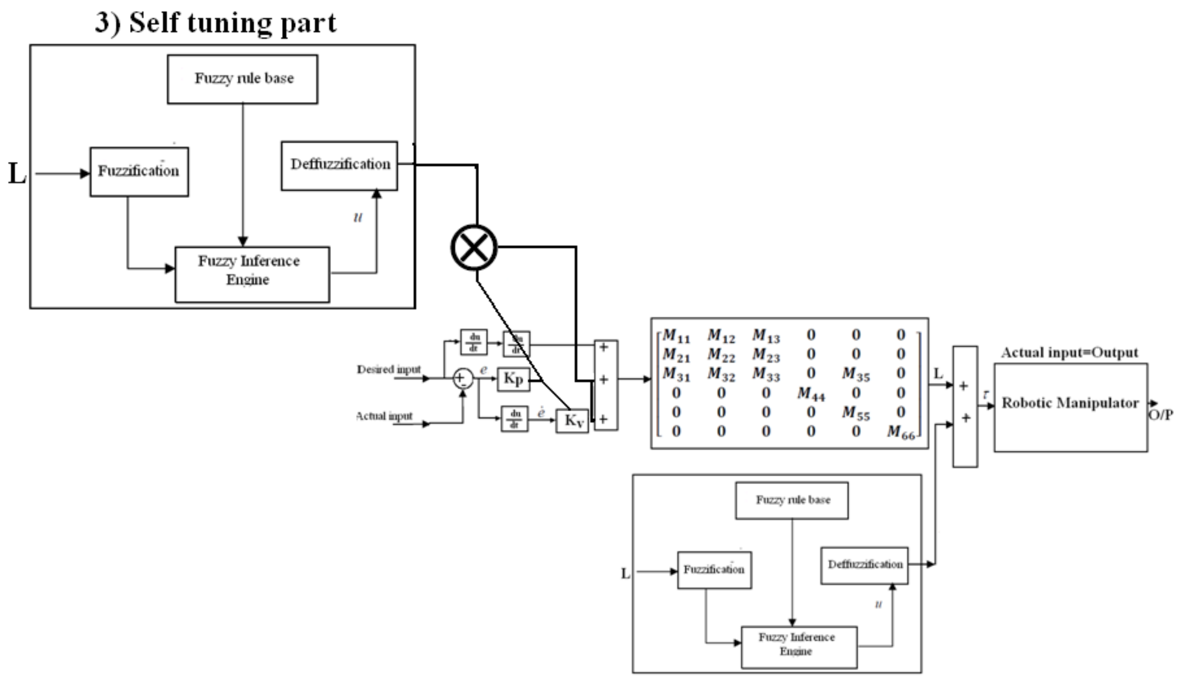

FIGURE 7: Block diagram of proposed gain tuning fuzzy computed torque like controller with minimum rule base in fuzzy nonlinear part and fuzzy supervisory.

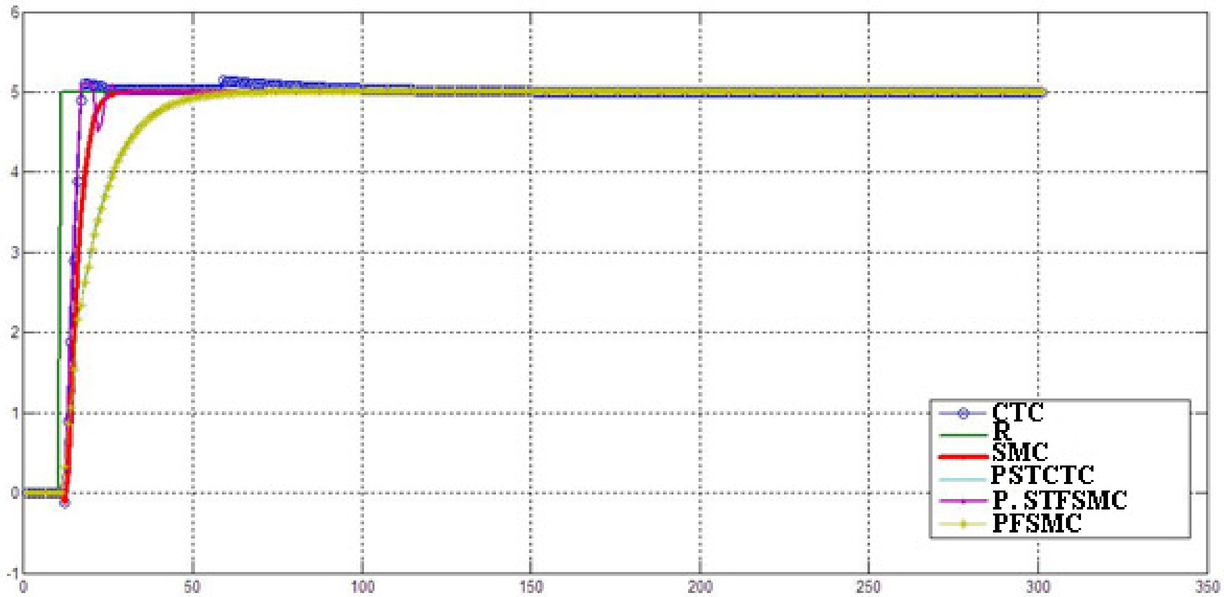

FIGURE 8 : first link step trajectory without disterbance

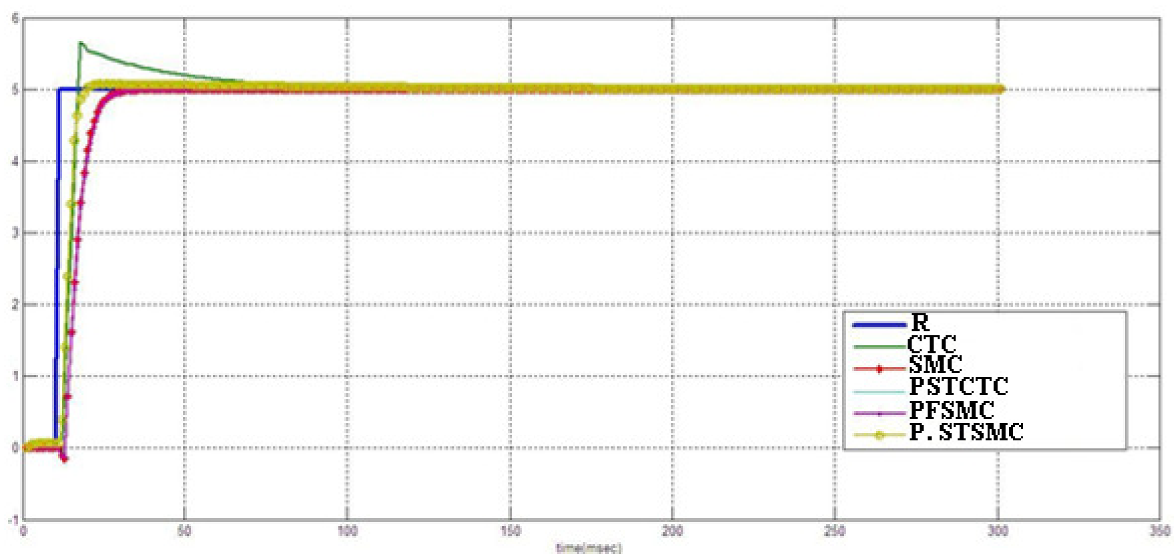

FIGURE 9: second link step trajectory without disterbance

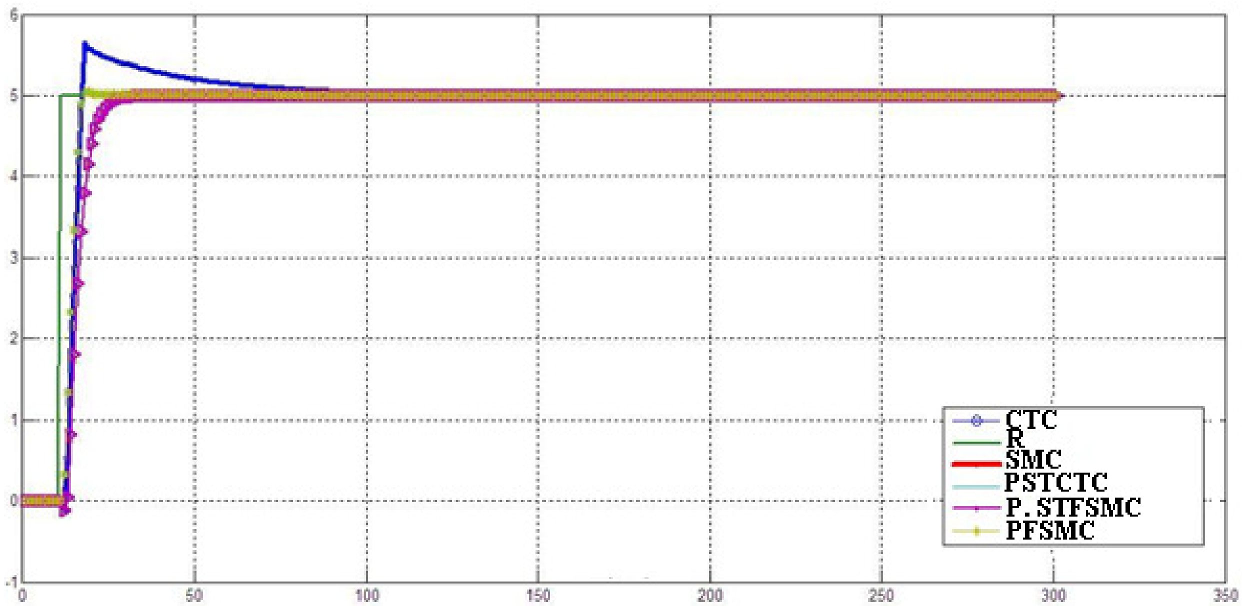

FIGURE 10 : Third link step trajectory without disterbance

Disturbance Rejection

Figure 11, 12 and 13 have shown the power disturbance elimination in above controllers. The main targets in these controllers are 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 response. It found fairly fluctuations in trajectory responses. As mentioned earlier, CTC and SMC works very well when all parameters are known, this challenge plays important role to select the GTCTLC and GTFSMC as a based robust controller in this research.

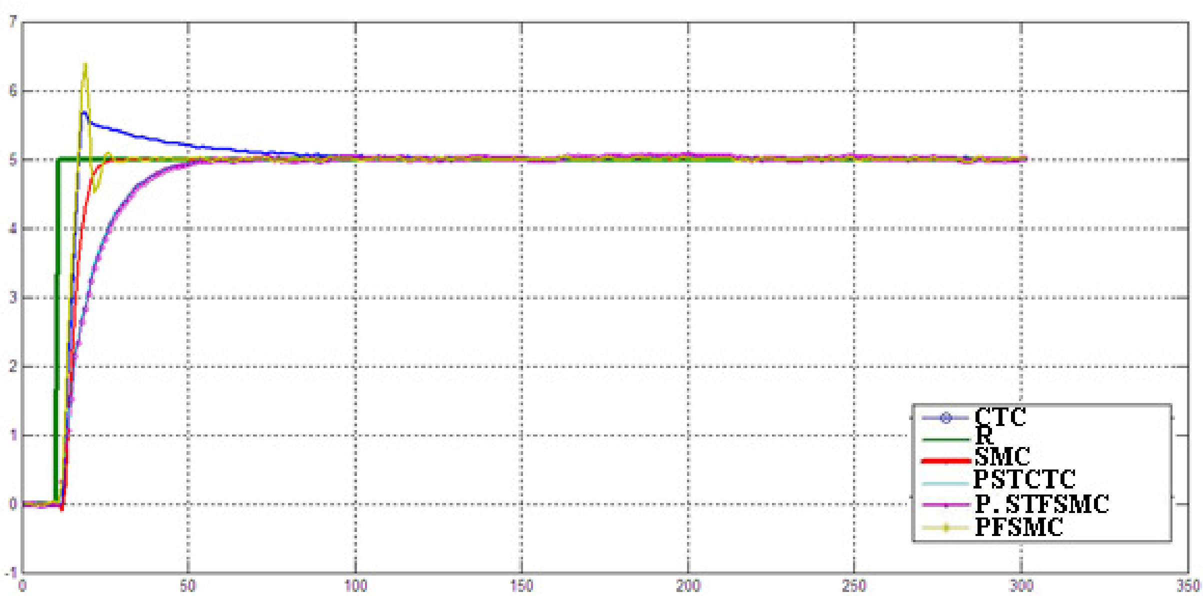

FIGURE 11 : First link step trajectory with disturbance

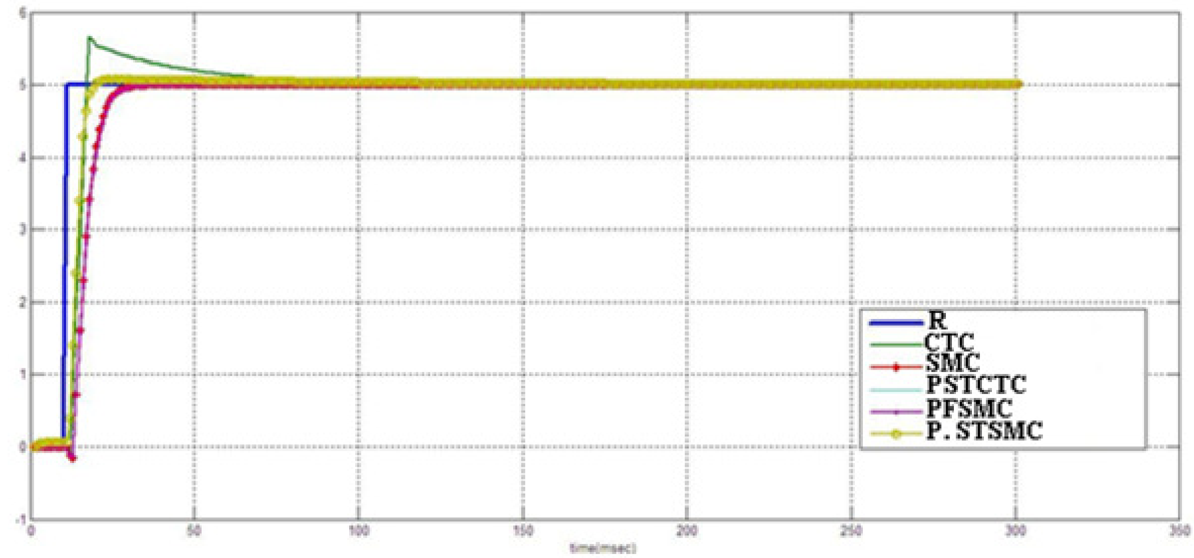

FIGURE 12: Second link step trajectory with disturbance

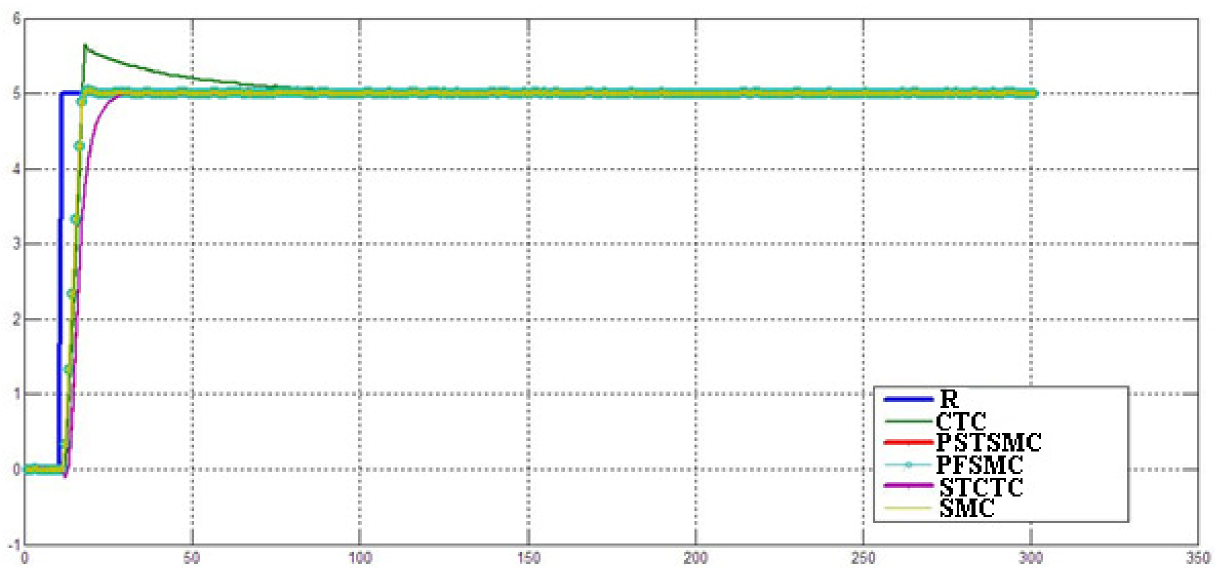

FIGURE 13: Third link step trajectory with disturbance

Errors in the Model: Figure 14 shows the tracking error for CTC, GTCTLC, SMC, FSMC, and GTFSMC. Equally, the proposed gain tuning computed torque like controller and proposed self tuning fuzzy sliding mode controller are more robust to changes of dynamic robot manipulator parameters value.

7. CONCLUSION

Refer to the research, a position artificial intelligence controller with tunable gain (GTCTLC and GTFSMC) 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 computed torque controller, sliding mode controller, fuzzy logic controller and tunable method, the performance has improved. Each method by adding to the previous controller has covered negative points. The system performance in computed torque controller, computed torque like controller, sliding mode controller and fuzzy sliding mode controller are sensitive to the gain updating factor. Therefore, compute the optimum value of gain updating factor for a system is the important challenge work. This problem has solved by adjusting gain updating factor of GTCTLC and GTFSMC. In this way, the overall system performance has improved with respect to the classical sliding mode controller and computed torque controller. This method solved chattering phenomenon as well as mathematical nonlinear equivalent part by applied fuzzy supervisory method.

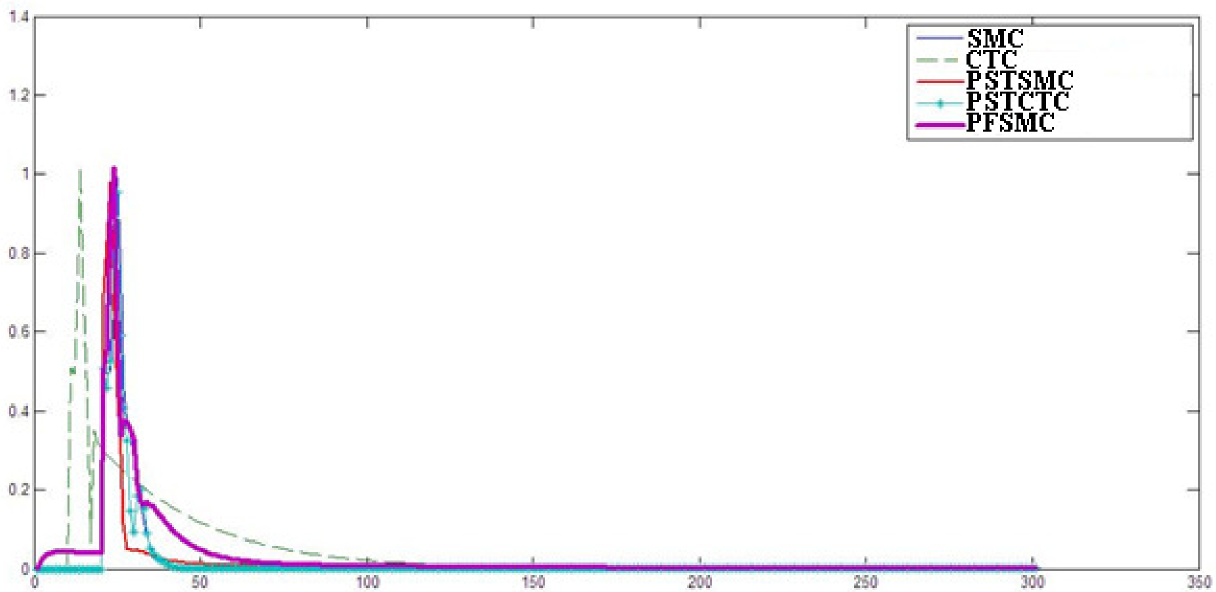

FIGURE 14: Errors in model

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