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Position control of robotic manipulator using SMC under uncertainties

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ABSTRACT

Precise control of robotic manipulator is a challenging problem. Robotic manipulators have highly non linear, time varying and highly coupled dynamics. Moreover there always exist uncertainty in the system model such as external disturbance, parameter uncertainty and sensor error. The present paper has focused to improve the trajectory tracking performance of rigid robotic manipulator under uncertainties. Sliding mode controller (SMC) with its various variants such as sliding mode controller with saturation function, with hyperbolic tangent function are implemented for trajectory tracking of robot manipulator. The performance of system with payload uncertainty and disturbances with these controllers (classic PID, Sliding mode controller (SMC) and Sliding mode controller with saturation function) are compared. Simulation shows that the Sliding mode controller shows the better performance than the PID controller especially with payload uncertainty and unknown disturbances. It has also been observed that the chattering problem present in control input of SMC can be eliminated by using saturation and hyperbolic tangent functions instead of signum function in SMC. Performance of these controllers has been compared in terms of various norms of tracking error and chattering in control input.

Keywords: PID Controller, robotic manipulator, sliding mode control, saturation function, hyperbolic tangent function, uncertainties.

I. INTRODUCTION

Robotics is a complex field involving many diverse discipline, such as physics, properties of materials, static and dynamics, electronics, control theory, signal processing, computer programming and manufacturing. The institute of robotic in The United States Of America defines the robot as " a reprogrammable, multifunctional manipulator design to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks"[1] [2]. Robot manipulators are composed of links connected by joints to form a kinematic chain. Joints are typically Rotary (revolute) or linear (prismatic).

Different types of control strategies ranging from simple classical control to robust control have been proposed by many researchers [3] [4]. Proportional integral derivative (PID) control is very popular among industry due to its simplicity and reliability [5] [6] have been used in various application [7]. Cervantes I. et. al. has proposed PID control for robotic manipulator [8]. A theoretical proof of PID stability for robotic manipulator has been provided by Rocco [9].

PID controller is not capable of giving desired response under feasible constraint. Under payload uncertainty and unknown disturbances, its performance deteriorates and it does not show the required robustness. Hence,

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there is need to explore the robust controllers for trajectory tracking problem of robotic manipulator which gives desired performance.

Robustness in nonlinear control can be effectively accomplished using sliding mode control (SMC) [2] [10]. But it has been observed that there is lot of chattering in the control effort, which is undesirable [11]. There are several methods to eliminate chattering from the control input. An attempt has been made in this paper to eliminate the chattering in control input of SMC by replacing the discontinuous signum function by saturation function and hyperbolic tangent function. Better performance and robustness is achieved in case of sliding mode control with its variants as compared to classic PID controller under the presence of uncertainties

The paper is organized in the following sections. The dynamics of robot manipulator is given in section 2. In section 3, control techniques such as PID, sliding mode control with signum function, with saturation function and with hyperbolic tangent function are explained. In sections 4, simulation results for position control of two link robotic manipulator using control techniques discussed above are given, followed by conclusion in section 5.

II. DYNAMIC MODEL OF THE SYSTEM

The dynamics of any n-link rigid robotic manipulator can be described in joint space by using Lagrangian approach the system dynamic model Inferred [1] [2].

$$M(q)\ddot{q} + C(q, \dot{q})\dot{q} + G(q) = \tau \qquad (1)$$

where q is the joint displacement vector. M (q) is the inertial matrix, C (q, $\dot{q}$) is the centripetal and coriolis terms. G(q) is a vector of gravity terms. It is assumed that mass of each link is concentrated at the midpoint of the respective link. τ is the control torque.

III. CONTROL STRATEGIES

The basic purpose of control strategy in position control of robot manipulator is to make the manipulator to follow a desired trajectory. Trajectory tracking error is defined as

$$e = q - q_d \qquad (2)$$

Where q_d is the desired trajectory.

The main objective of various control strategies is to minimize the tracking error of robotic manipulator under various uncertain conditions.

3.1 PID CONTROL

PID controllers are commercially successful and widely used controllers in industries. Here the purpose of PID controller is to make the manipulator to follow a desired trajectory with minimum possible error. Fig.1 shows the block diagram of PID controller with robot manipulator.

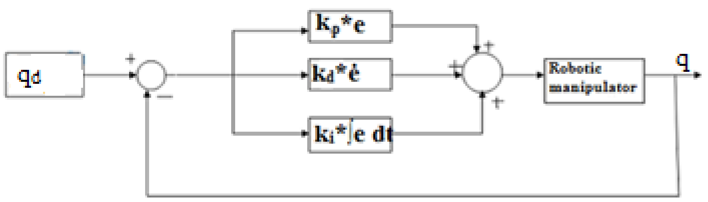

Fig.1. Functional block diagram of PID controller

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PID control law is described by equation shown below as (3) [12]

$$\tau = k_p * e + k_d * \dot{e} + k_i * \int e\,dt \qquad (3)$$

where e is the error matrix. k_p, k_d and k_i are proportional, derivative and integral gains respectively [12].

3.2 SLIDING MODE CONTROLLER

One particular approach to robust controller design is the sliding mode control methodology. The idea behind sliding mode control is to choose a suitable surface in the state space, typically a linear hyper surface, called the switching surface and switch the control input on this surface [13].The control input is then chosen to guarantee that the trajectories near the sliding surface are directed toward the surface.

The design of a sliding mode control law can be divided into two steps:

(i) Define a suitable sliding surface, $s = 0$

(ii) Determine the system dynamics on the surface

Defining the sliding surface s as [13]

$$s = \dot{e} + \lambda e \qquad (4)$$

Differentiating (4), we get

$$\dot{s} = \ddot{e} + \lambda \dot{e} \qquad (5)$$

where λ is a positive definite matrix.

To setup τ, defining the reference state

$$\dot{q}_r = \dot{q} - s \qquad (6)$$

Differentiating (6), we get

$$\ddot{q}_r = \ddot{q} - \dot{s} \qquad (7)$$

Based on the equivalent control and in order to achieve the zero error object a sliding mode control law [11] [14] is formed as

$$\tau = \hat{\tau} + \tau_s \qquad (8)$$

$$\hat{\tau} = \hat{M}\ddot{q}_r + \hat{C}\dot{q}_r + \hat{G} + \hat{F} - As \qquad (9)$$

$$\tau_s = -K * sgn(s) \qquad (10)$$

where $\hat{M}$, $\hat{C}$, $\hat{G}$ and $\hat{F}$ are the nominal matrices. K and A are diagonal positive definite matrix. $\hat{\tau}$ is called equivalent control.

3.3 SMC WITH SATURATION FUNCTION

In order to eliminate the control input chattering problem, first order sliding mode control with saturation function is used [15] by replacing the signum function in eq. (10) by saturation function shown below in eq. (11)

$$\text{sat}(\xi) = \begin{cases} 1 & \xi \geq 1 \\ \xi & -1 < \xi < 1 \\ -1 & \xi \leq -1 \end{cases}$$

where $\xi = s/\beta$ and

$$\tau_s = -K * sat(\xi) \qquad (11)$$

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3.4 SMC WITH HYPERBOLIC TANGENT FUNCTION

In order to eliminate the control input chattering problem, first order sliding mode control with hyperbolic tangent function is used [16][17] by replacing the signum function in eq. (10) by hyperbolic tangent function shown below in eq. (12)

$$\tanh(\eta)=\begin{cases} 1 & \eta \geq 1 \\ \tanh(\eta) & -1<\eta<1 \\ -1 & \eta \leq -1 \end{cases}$$

where $\eta = s\alpha$ and

$$\tau_s = -K * \tanh(\eta) \qquad (12)$$

IV. SIMULATION RESULTS AND DISCUSSION

The objective of this study is the trajectory tracking control of two link robotic manipulator i.e. to track the desired trajectory using various control techniques. The desired trajectories chosen are $q_{d1} = \sin(t)$ for joint1and $q_{d2} = \cos(t)$ for joint 2. The control techniques (PID, SMC, SMC with saturation function and SMC with hyperbolic tangent function) presented above has been successfully implemented for tracking control of two link manipulator under various uncertainties such as pay load (20 % of mass) and disturbance torque . The external disturbances considered are $\tau_{d1} = 0.2\sin(2t)$ and $\tau_{d2} = 0.2\cos(2t)$.

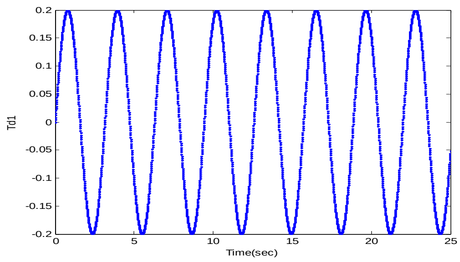

Fig.2. Disturbance torque for joint 1 (τ_{d1})

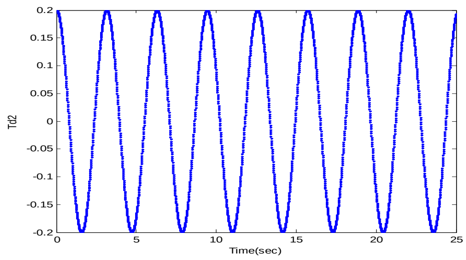

Fig.3. Disturbance torque for joint 2 (τ_{d2})

The parameters of two link planar robotic manipulator considered here for simulation in MATLAB, are listed in table 1

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Table 1 Parameters of Two Link Robotic Manipulators

Parameter	Symbol	Value and unit
Mass of link 1	m_1	1kg $\pm$ 0.2 kg
Mass of link 2	m_2	1kg $\pm$ 0.2 kg
Length of link 1	l_1	1.0m
Length of link 2	l_2	1.0 m
Gravity constant	g	9.81g/s^2

4.1 SIMULATATION RESULTS USING PID

Simulation results for position control of two link robotic manipulator using PID control technique with 20% payload uncertainty and disturbances are shown below. For simulation, the value of k_p, k_d and k_i for PID controller are selected by trial and error method as k_p =[250 0;0 250], k_i =[40 0;0 40], k_d =[20 0;0 20]

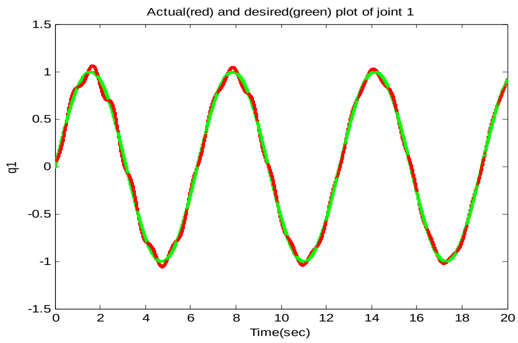

Fig.4.Tracking of q1

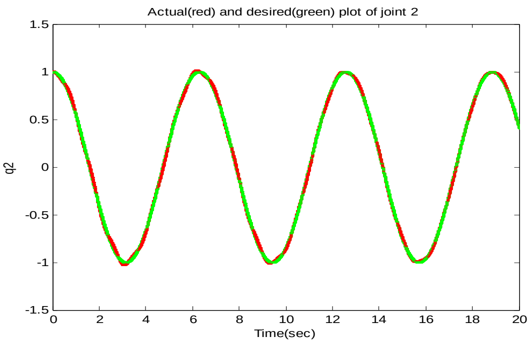

Fig.5.Tracking of q2

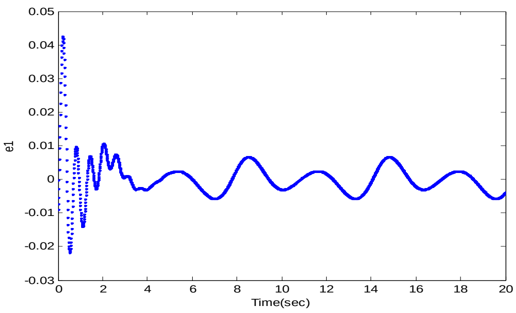

Fig.6.Tracking error of joint1 (e_1)

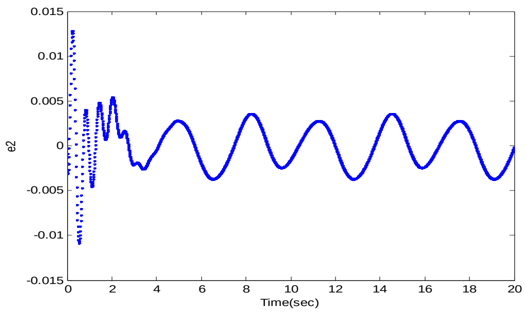

Fig.7.Tracking error of joint 2 (e_2)

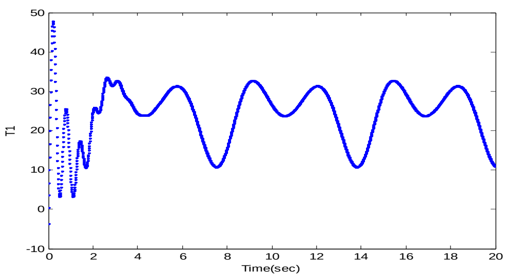

Fig.8. Control input of joint 1 (τ_1)

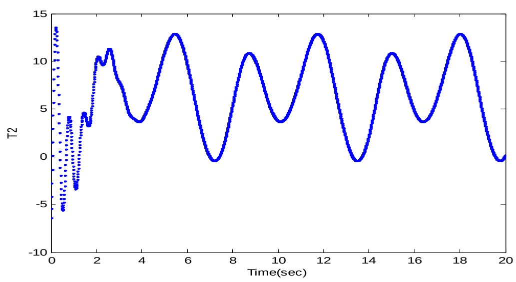

Fig.9.Control input of joint 2 (τ_2)

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Fig.4 and Fig.5 shows the actual (red) and desired (green) trajectory of joint 1 and joint 2. Fig.6 and Fig.7 shows the plot of tracking error for joint1and joint 2. Fig.8 and Fig.9 shows the plot of control input of joint1 and joint 2.

4.2 SIMULATION RESULTS USING SMC

Simulation results for position control of two link robotic manipulator using SMC control technique with 20% payload uncertainty and disturbances are shown below. Values of K, A and ʎ for SMC selected as K=[15 0;015], A=[50 0;0 50] and ʎ =[10 0;0 10].

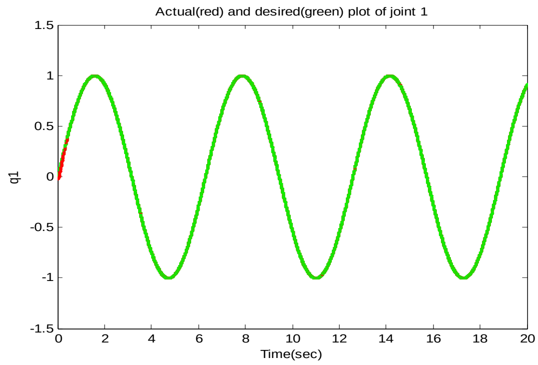

Fig.10.Tracking of q1

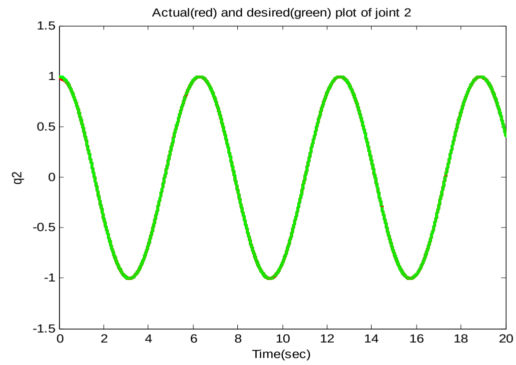

Fig.11.Tracking of q2

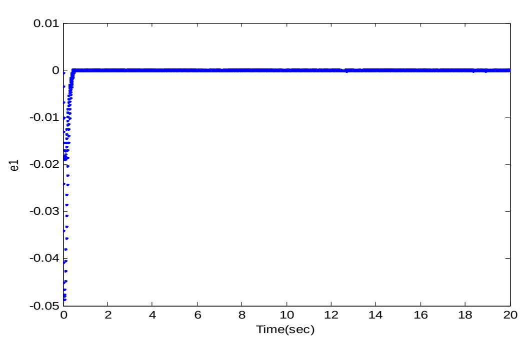

Fig.12.Tracking error of joint1(e_1)

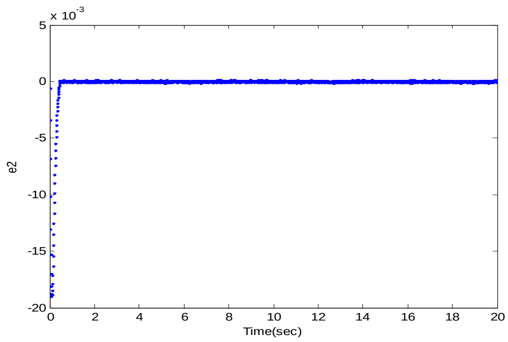

Fig.13.Tracking error of joint2 (e_2)

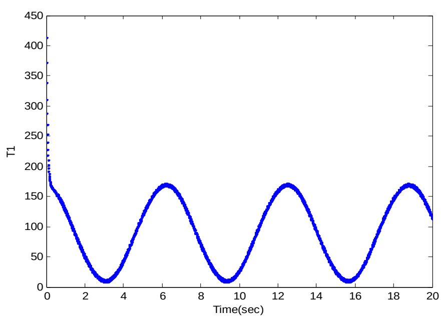

Fig.14.control input of joint 1 (τ_1)

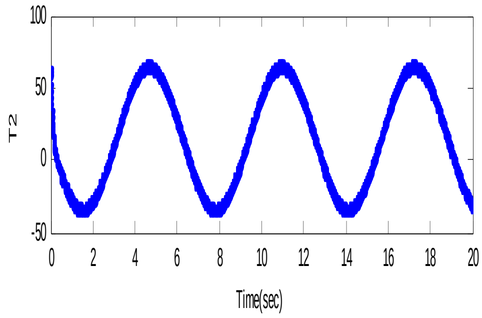

Fig.15.control input of joint 2 (τ_2)

Fig.10 and Fig.11 Shows the actual (red) and desired (green) trajectory of joint 1 and joint 2. Fig.12 and Fig.13 shows the plot of tracking error for joint1and joint 2. Fig.14 and Fig.15 shows the plot of control input of joint1 and joint 2.

4.3 SIMULATION RESULTS USING SMC WITH SATURATION FUNCTION

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Simulation results for position control of two link robotic manipulator using SMC with saturation function control technique with 20% payload uncertainty and disturbances are shown below. Values of K, A and λ for SMC selected as K= [15 0;0 15], A=[50 0;0 50], λ =[10 0;0 10] and β =0.2.

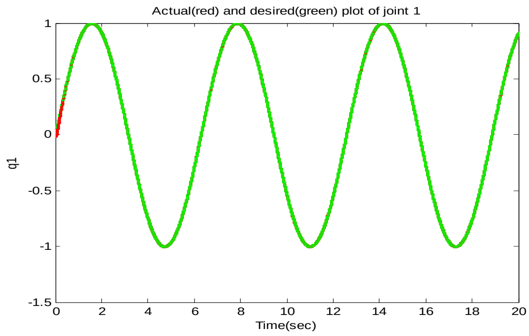

Fig.16. Tracking of q1

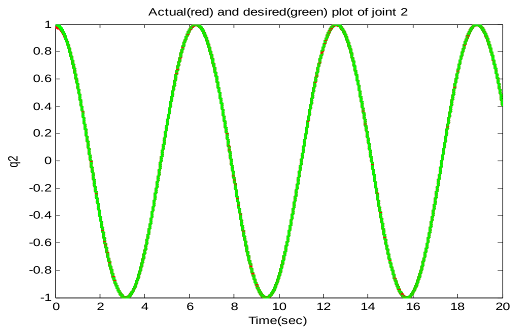

Fig.17. Tracking of q2

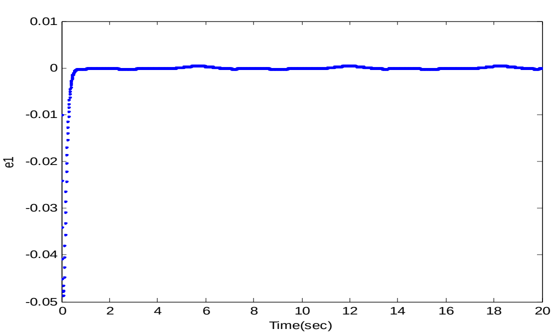

Fig.18.Tracking error of joint 1 (e_1)

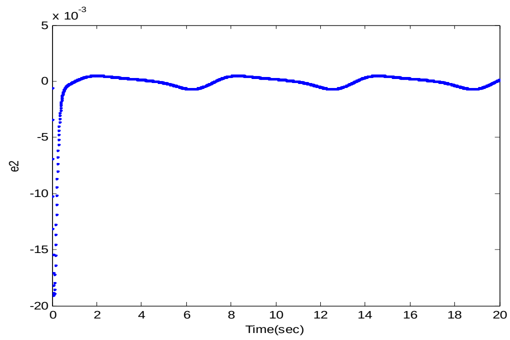

Fig.19.Tracking error of joint 2 (e_2)

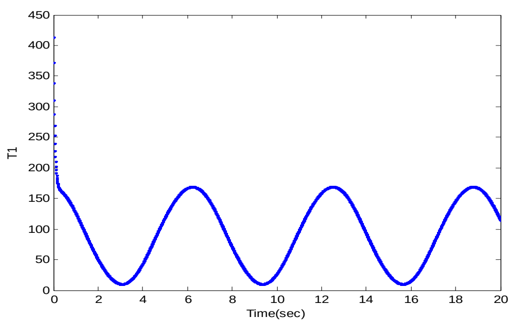

Fig.20.control input of joint 1 (τ_1)

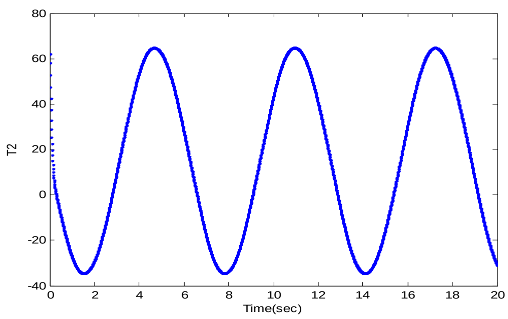

Fig.21.control input of joint 2 (τ_2)

Fig.16 and Fig.17 Shows the actual (red) and desired (green) trajectory of joint 1 and joint 2. Fig.18 and Fig.19 shows the plot of tracking error for joint1and joint 2. Fig.20 and Fig.21 shows the plot of control input of joint1 and joint 2.

4.4 SIMULATION RESULTS USING SMC WITH HYPERBOLIC TANGENT FUNCTION

Simulation results for position control of two link robotic manipulator using SMC with hyperbolic tangent function control technique with 20% payload uncertainty and disturbances are shown below. Values of K, A and λ for SMC selected as K=[15 0;015], A=[50 0;0 50], λ =[10 0;0 10] and $\alpha = 0.2$.

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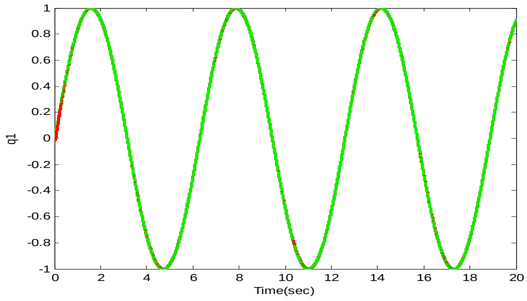

Fig.22. Tracking of q1

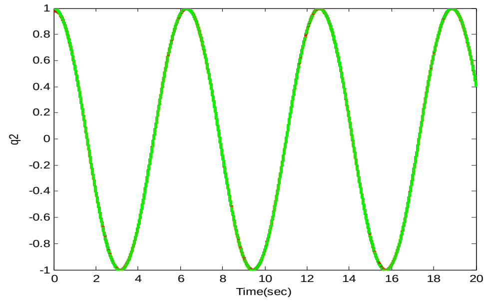

Fig.23. Tracking of q2

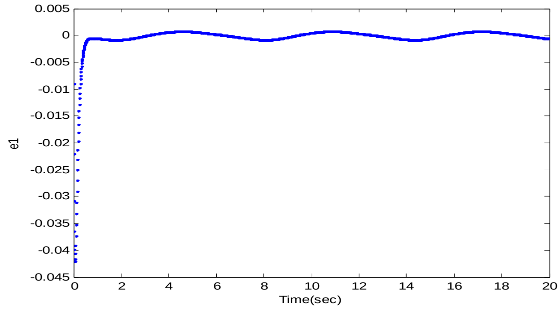

Fig.24.Tracking error of joint 1(e_1)

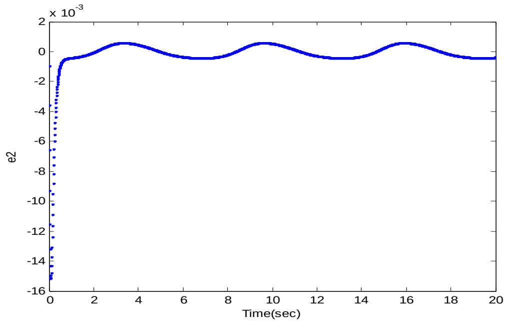

Fig.25.Tracking error of joint 2 (e_2)

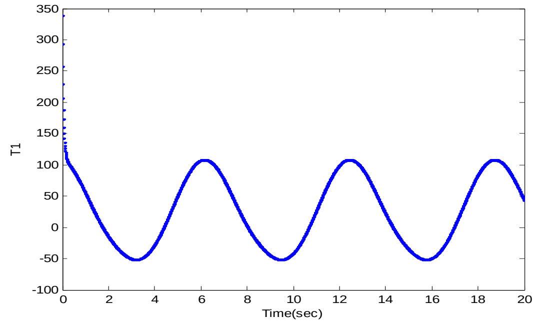

Fig.26.control input of joint 1 (τ_1)

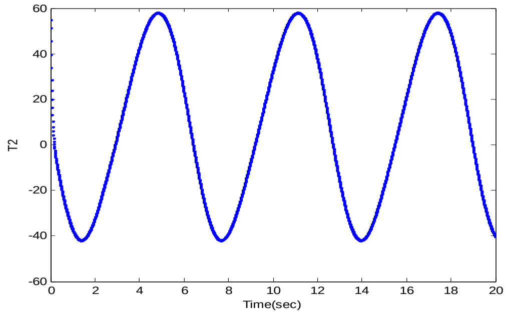

Fig.27.control input of joint 2 (τ_2)

Fig.22 and Fig.23 Shows the actual (red) and desired (green) trajectory of joint 1 and joint 2. Fig.24 and Fig.25 shows the plot of tracking error for joint1and joint 2. Fig.26 and Fig.27 shows the plot of control input of joint1 and joint 2.

Table 1.Performance indices

	Joint 1					**Joint 2**				
	$L[e_1]$	e_1^m	$L^2[e_1]$	$L[\tau_1]$	$C[\tau_1]$	$L[e_2]$	e_2^m	$L^2[e_2]$	$L[\tau_2]$	$C[\tau_2]$
PID	0.0166	0.593	0.609	66.71	1.21	0.0027	0.015	0.033	10.43	0.294
SMC with sign. fun.	0.0035	0.045	0.514	20.37	0.023	0.0011	0.0037	0.013	9.42	0.041
SMC with sat. fun.	0.0024	0.026	0.297	20.39	0.0069	0.0010	0.0054	0.122	9.45	0.0014
SMC with tanh fun.	0.0023	0.0254	0.299	20.35	0.0067	0.0011	0.0006	0.126	9.44	0.00138

Where L[e], e^m, L^2[e], L[τ] and C[τ] represent the average tracking error, maximum error, 2-norm of error, average torque and degree of chattering respectively. Table.1. shows the performance indexes for the following control technique such as PID, SMC, SMC with saturation function and SMC with hyperbolic tangent function. From table.1 it has been concluded that the values of control input is much higher in case of PID control technique and from mechanical consideration of actuator this is much higher gain is not realizable. SMC work well but there is chattering in control input. SMC with saturation function or SMC with hyperbolic tangent function eliminate the chattering problem.

V. CONCLUSIONS

In this paper, various control techniques such as classical PID, sliding mode control, sliding mode control with saturation function and sliding mode control with hyperbolic tangent function for tracking a desired trajectory by a two link rigid robotic manipulator with payload uncertainty and unknown disturbances is presented. Under unknown disturbances, the PID controller does not always exhibit good accuracy and robustness properties. PID can be used where accuracy of tracking is not much important. For robotic manipulator where accuracy is highly desirable, other control techniques have to be explored. Sliding mode control provides robustness properties in non linear control of 2-link manipulator against payload uncertainty and unknown disturbances. But it has been observed that there is a lot of chattering in the control effort, which is undesirable. In this paper, sliding mode controller has been designed for two link robotic manipulator. In SMC, chattering is one of major drawback. To overcome this challenge, we have replaced signum function by saturation function or hyperbolic tangent function. These modifications bring reduction in chattering of control input and hence improve the performance of robotic manipulator for trajectory tracking.

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