Integrating A Few Actions For Chattering Reduction And Error Convergence In Sliding Mode Controller In Robotic Manipulator

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Abstract

Various techniques used for chattering elimination in Sliding Mode Controller (SMC) have been studied and summarized in this paper. Various advantages of sliding mode controller (SMC) includes robustness, ability to deal with non-linear, time varying and multi- input, multi-output systems. SMC can also be designed for the fast dynamic response and good stability over a wide range. In spite of this, one of the main hindrances in the implementation of the sliding mode controller (SMC) is the chattering. Chattering; most of the times is undesirable, as it excites the unmodeled high frequency dynamics of the system. In order to overcome these drawbacks, this paper contains a brief review of a few techniques in research used for chattering elimination in SMC. Implementations of a few chattering reduction techniques and their validation results over the basic SMC have been proved.

Keywords: *Sliding Mode Controller, Saturation Function, Pseudo Sliding Function, Hyperbolic Tangent Function (HTF).*

I. INTRODUCTION

Sliding Mode Controller (SMC) theory was first appeared outside Russia in 1976 [1, 2]. Distinguishing feature of robustness of SMC has made this controller of worldwide interest. In many practical problems, almost perfect disturbance rejection and set point tracking are required. SMC may be applied to such systems to obtain these performances.

However the SMC has a serious drawback of chattering. Because the control input in SMC includes the signum function, it induces the chattering signal [3]. The chattering involves extremely high control activity and increase electric power consumption. In addition, the chattering produces undesirable highly nonlinearity of the system dynamics. Elimination or reduction of chattering has charmed significantly many researchers [7, 8, 9]. After so many years of research still this chattering problem till remains unsolved and need to be worked upon. The boundary layer phenomenon is used to avoid chattering phenomena [4]. The cost of this technology is a reduction in the accuracy of the tracking performance [5, 6].

In this paper, sliding mode control with PID sliding surface with many different functions for robot manipulators have been presented. The advantage of proposed methods is not only insensitive to parameter variations and external disturbances (uncertainties) but also improves the performance of the SMC in terms of chattering phenomenon. The chattering phenomenon is eliminated by the functions naming 1. saturation function, 2. pseudo sliding function with smooth control action, 3. hyperbolic tangent function in place of pure signum function. The results given in the end of the paper indicate that the control performance is satisfactory.

Section II describes about basic dynamics of the robotic manipulator, Section III contains various controllers to be implemented, Section IV has simulations and results, and Section V has valuable conclusions in it.

II. ROBOT MANIPULATOR MODEL

Consider an *n*-link robot manipulator, which takes into account the friction forces and disturbances, with the equation of motion given by [10],

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

with $q \in R^n$ as the joint angular position vector of the robot manipulator $\in R^n$ as vector of input torques; $M(q) \in R^{nxn}$ is the inertia matrix which is symmetric and positive definite; $V(q,\dot{q}) \in R^{nxn}$ is the coriolis and centripetal forces matrix and $G(q) \in R^n$ includes the gravitational forces.

III. CONTROLLER DESIGNS

Sliding Mode Controller

Taking the controller design problem as follows. Given the desired trajectory q_d with some system parameters being unknown, the aim is to derive a control law for the torque input τ. Such that the position vector q can track the desired trajectories.

Let the tracking error vector be

$$e = q - q_d, e \in R^n; \quad (2)$$

The conventional sliding mode control used sliding function definition involving the position error and the velocity error of the form

$$\sigma(t) = \dot{e} + \Lambda_1 e \quad (3)$$

In this paper, the sliding function is extended to include the integral error term. Therefore, the sliding function is defined as

$$\sigma(t) = \dot{e} + \Lambda_1 e + \Lambda_2 \int_0^t e \ dt \quad (4)$$

where Λ_1 and Λ_2 are constant positive definite diagonal matrices [11].

$$\beta(t) = \sigma(0) \exp(-\alpha t) \quad (5)$$

where $\propto > 0$, and $\beta(0) = \dot{e}(0) + \Lambda_1 \dot{e}(0)$

The function $\beta(t)$ drives system states in any state space directly to the sliding mode without a reaching phase. In other words, the system states are initially located in the sliding mode. If system states are maintained on the surface for $t > 0$, then e approaches zero and $q \rightarrow q_d$.

Torque equation for SMC is defined as

$$\tau = -M\left(\Lambda_1 \dot{e} + \Lambda_2 e - \ddot{q}^d + \dot{\beta}\right) + V\left(\dot{q}^d - \Lambda_1 e - \Lambda_2 \int_0^t e \ dt\right) + G - A\sigma - K \quad (6)$$

where $A=[a_1, a_2 \ldots . a_n]$, a_i is a positive constant, and

$$K=-k \operatorname{sgn}(\sigma) \quad (7)$$

$$\text{with } \operatorname{sgn}(\sigma) = \begin{cases} 1, & s > 0 \\ 0, & s = 0 \\ -1, & s < 0 \end{cases} \quad (8)$$

And k: a positive constant that represent the discontinuous constant gain.

Chattering phenomenon

During sliding mode control implementation, control engineers may experience the undesirable phenomenon of oscillations with finite frequency and amplitude, which is known as 'chattering'. There are two causes of chattering. First, there may be fast dynamics which were neglected in the ideal model and these unmodeled dynamics are from servomechanisms, sensors and data processors with small time constants. Second, in digital control system, microcontrollers having finite sampling rates are used, which causes so called 'discretization chattering'. In this paper, the first case, chattering in the presence of unmodeled dynamics, is discussed. This highly undesirable behavior may excite the high frequency unmodeled dynamics which could result in unforeseen instability, and can cause damage to actuators or to the plant itself.

In this research paper, a review of various chattering reduction techniques have been discussed and analyzed, in which a pure signum function has been replaced with saturation, pseudo sliding and tangent hyperbolic function. These functions have been explained one by one as:

Saturation Function: The sgn (σ) is replaced by the sat (σ/δ), where δ is boundary layer [12] and

$$\operatorname{sat}(\xi) = \begin{cases} 1, & \xi \geq 1 \\ \xi, & -1 < \xi < 1 \\ -1, & \xi \leq -1 \end{cases} \quad (9)$$

Pseudo Sliding Function: One can consider pseudo sliding control function as

$$K=-k \frac{\sigma}{|\sigma|+\delta} \quad (10)$$

where δ is a small positive scalar also called as tuning parameter which is used to reduce the chattering and its value is between 0 to 1. It can be analyzed from (10) that as $\delta \rightarrow 0$, function K tends to be a pure signum function [13]. Hence, value of δ is of great significance. It is a tradeoff between the requirements of maintaining ideal performance with that of ensuring a smooth control action.

Hyperbolic Tangent Function (HTF): In spite of using a chattering causing discontinuous signum function, a HTF function defined as (11) can be used. The control gain is now

$$K=-k \frac{e^{\alpha\sigma}-e^{-\alpha\sigma}}{e^{\alpha\sigma}+e^{-\alpha\sigma}} = \tanh(\alpha\sigma) \quad (11)$$

where α is the positive parameter to control the shape of the function[14]. For this function boundary layer is expressed as:

$$K=\begin{cases}-k\tanh(\alpha\sigma), & |\sigma|<1\\ -k\,\mathrm{sgn}(s), & \text{otherwise}\end{cases} \qquad (12)$$

IV. SIMULATIONS EXAMPLE AND RESULTS

In order to show the effectiveness of the proposed control law, it is applied to two-link robot with the parameters given below. The dynamics of a 2 DOF manipulator used in all types of controllers and satisfying Eq. (1) is given as

$$M(q)=\begin{bmatrix}8.77+1.02*\cos q2 & 0.76+.51*\cos q2\\ 0.76+.51*\cos q2 & 0.62\end{bmatrix} \qquad (13)$$

$$V(q,\dot{q})=\begin{bmatrix}-.51\sin(q2)\dot{q}2 & -.51\sin(q2)(\dot{q}1+\dot{q}2)\\ -.51\sin(q2)\dot{q}1 & 0\end{bmatrix} \qquad (14)$$

$$G(q)=\begin{bmatrix}74.48\sin(q1)+6.174\sin(q1)+q2\\ 6.174\sin(q1)+q2\end{bmatrix} \qquad (15)$$

This 2 DOF manipulator has commanded to track the path shown given by in Fig.1-2 and given by the equation below

$$q^{d}_{1}=[.3\sin(.7t-\Pi/2)+.3\sin(.1t-\Pi/2)+.7]; \qquad (16)$$

$$q^{d}_{2}=[.5\sin(.9*t-\Pi/2)+.5\sin(.1t-\Pi/2)+1.1]; \qquad (17)$$

The sampling time is taken as 0.001 for the whole simulation. In order to acquire the desired response of the output of the manipulator sliding function constants are taken as

$$\Lambda_1=\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix} \text{ and } \Lambda_2=\begin{bmatrix}20 & 0\\ 0 & 20\end{bmatrix} \qquad (18)$$

The control gain in (7) for the simulation in this paper is taken as

$$k=\begin{bmatrix}20 & 0\\ 0 & 10\end{bmatrix} \qquad (19)$$

The positive constant matrix A is taken as

$$A=\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix} \qquad (20)$$

For saturation function boundary layer constant δ is taken as 0.1.

In pseudo sliding function, the positive constant δ is assumed to be; δ = [.2 .23].

For HTF, constant α is taken to be unity.

Output tracking path covered by the robotic manipulator by applying different control functions in SMC has been represented in Fig. 3&4. Curves representing continuous tracking error for joint 1 and joint 2 using various controllers can been observed in Fig. 5&6 respectively. Simulation results for torques of joint 1&2 for four different controllers have been represented in Fig. 7-14.

A summary table for error comparison of various controllers is given as Table 1 for joint 1 and Table 2 for joint 2.

Seen from the figures and tables, it can be said that chattering has been reduced to a significant level in all the three proposed functions. In these, three functions chattering is minimum in pseudo sliding function when compared to others with a small rise in error. Error is minimum and chattering is maximum in SMC as compared to other control actions.

V. CONCLUSION

In this paper, a robust SMC-PID controller has been designed and implemented considering all its advantages and disadvantages. Integral action has been included in sliding function. This controller has a great input chattering effect. This input chattering has been removed by using 1. Saturation function 2. Pseudo sliding function, 3. Hyperbolic tangent function in place of pure signum function. Simulation results have shown that chattering phenomenon has almost been nullified without much increase in error.

Hence, may be recommended to use these control functions in SMC for further work.

Table 1: Error for Joint 1

SMC	min error	max error	mean error	mse
Signum	-0.0793	0.0001	-0.03	.0011
Saturation	-0.00099	0.00566	-0.0027	1 e-05
Pseudo	-0.0189	0.00018	-.01135	-.0189
HTF	-0.00019	0.0066	-0.0035	1.5e-5

Table 2: Error for Joint 2

SMC	min error	max error	mean error	mse
Signum	-.0006	0.077	0.0294	0.0011
Saturation	-.0061	-5.3 e-5	-0.0024	8.9 e-5
Pseudo	-0.001	0.0184	-0.010	-0.0010
HTF	-.007	-5.3 e-5	-0.0032	1.37 e-05

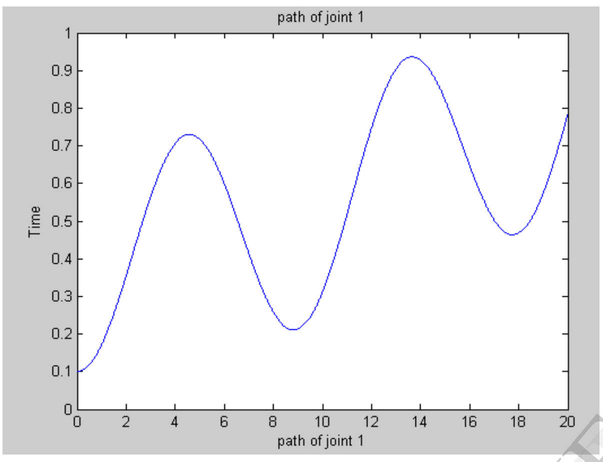

Fig. 1 Path to be covered by J1

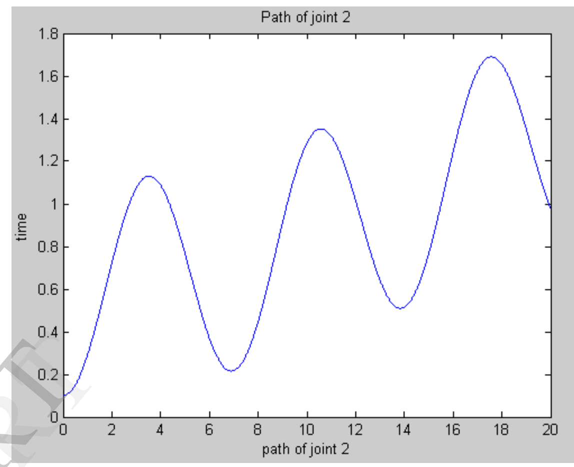

Fig. 2 Path to be covered by J2

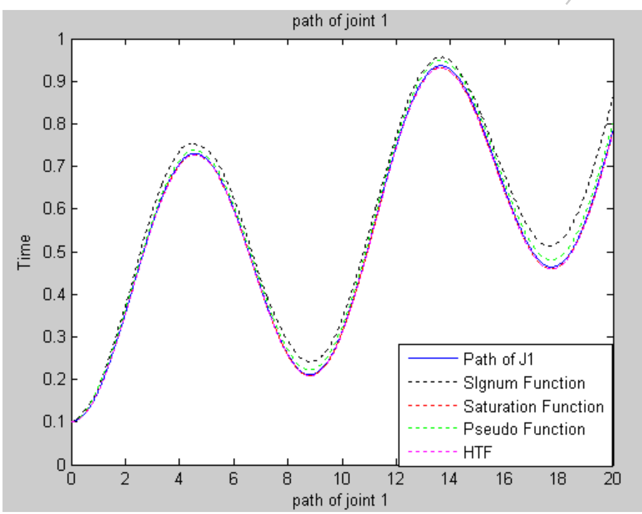

Fig. 3 Output Tracking of controllers for J1

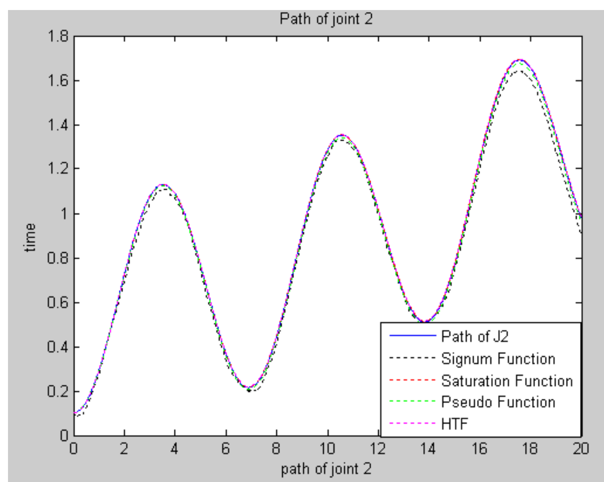

Fig. 4 Output Tracking of controllers for J2

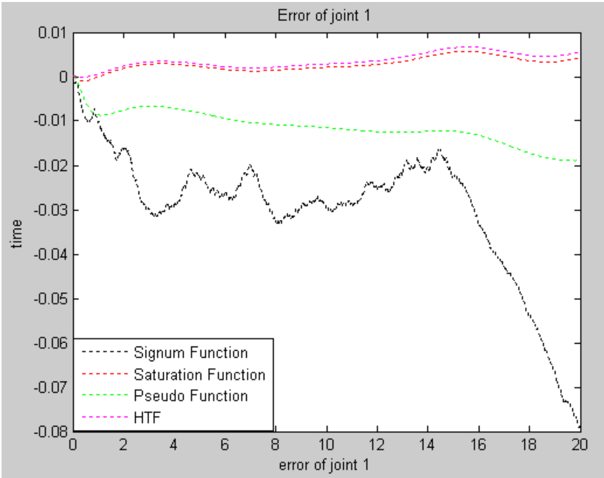

Fig. 5 Tracking error for J1

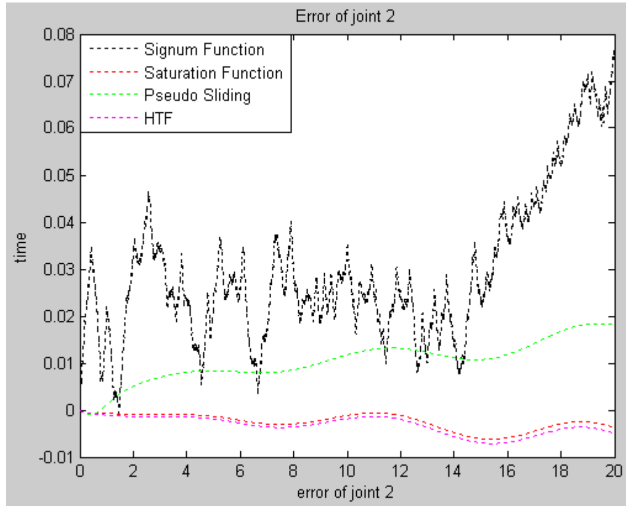

Fig. 6 Tracking error for J2

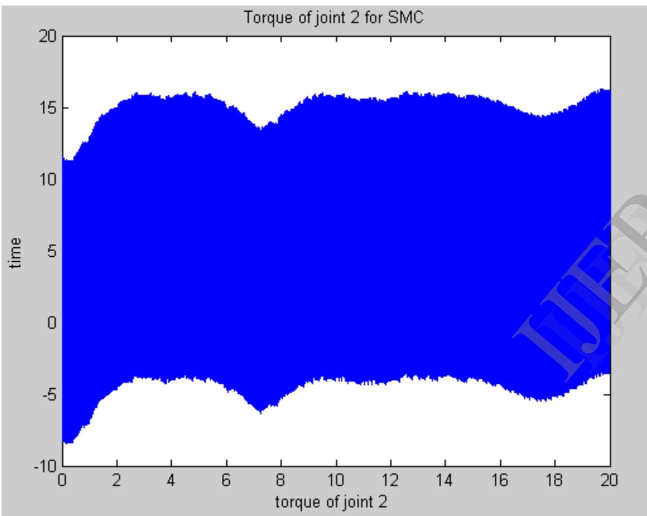

Fig. 7 Torque of J1 with Signum Function

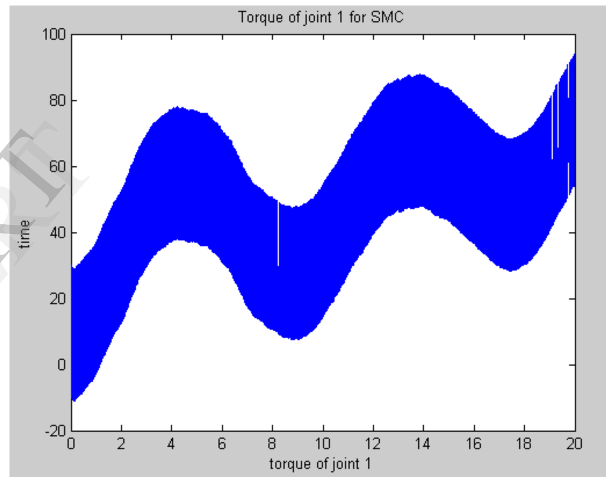

Fig.8 Torque of J2 with Signum Function

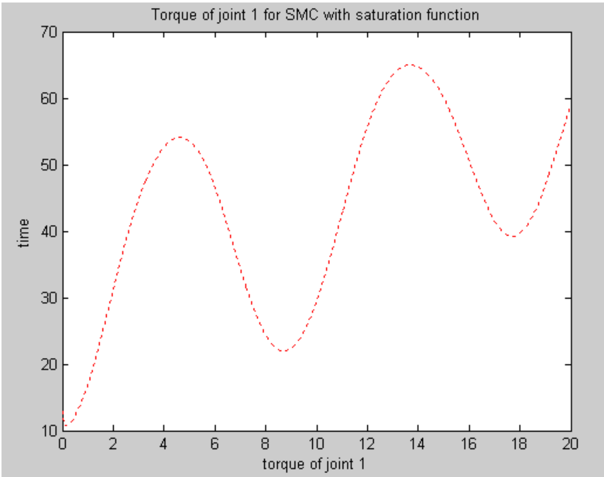

Fig. 9 Torque of J1 with Saturation Function

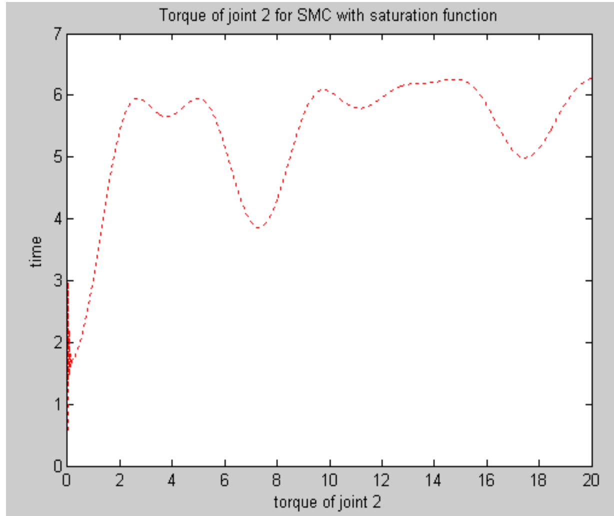

Fig. 10 Torque of J2 with Saturation Function

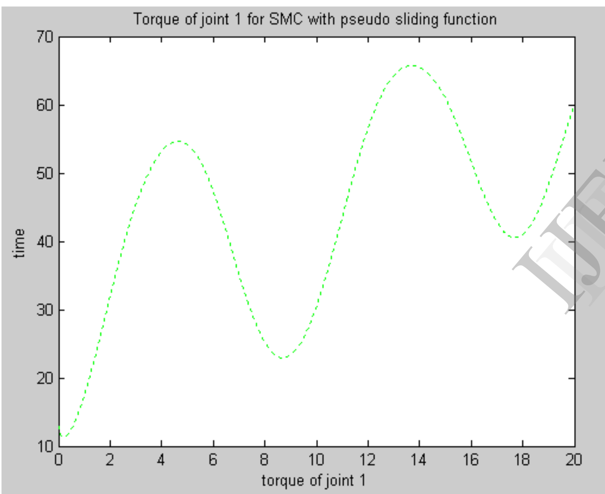

Fig. 11 Torque of J1 with Pseudo Function

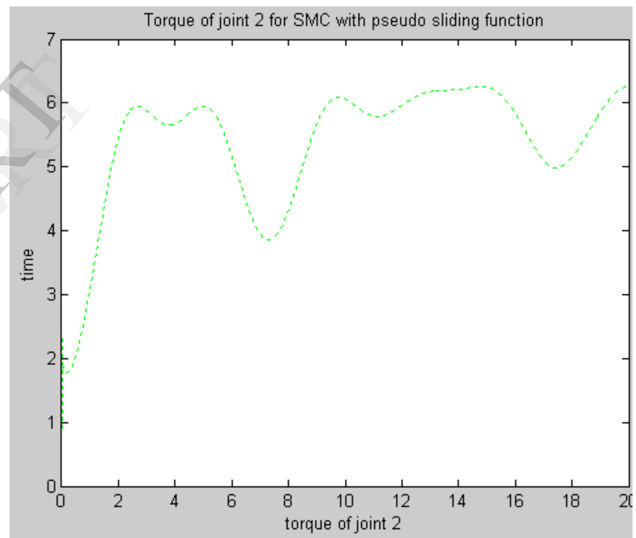

Fig. 12 Torque of J2 with Pseudo Function

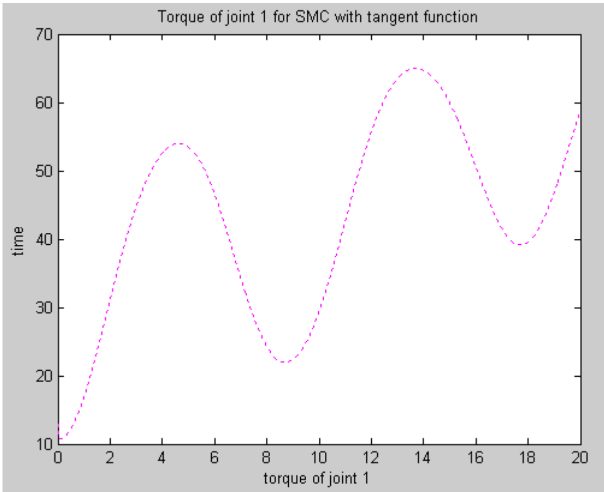

Fig. 13 Torque of J2 with HTF

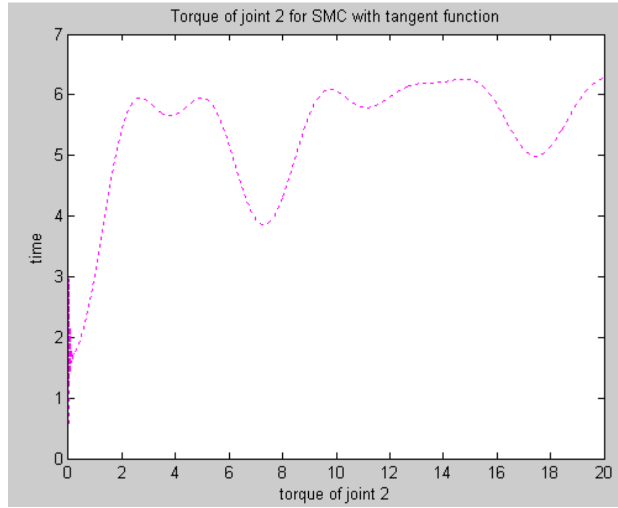

Fig. 14 Torque of J2 with HTF

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