Comparison of Conventional & Fuzzy based Sliding Mode PID Controller for Robot Manipulator

Dhaval Vyas , Jyoti Ohri and Ankit Patel

Abstract— **High accuracy trajectory tracking is challenging topic in robotic manipulator control. This is due to nonlinearities and input coupling present in robotic arm. In this paper, a chattering free sliding mode control (SMC) for a robot manipulator including PID part with a fuzzy tunable gain is designed. The main idea is that the robustness property of SMC and good response characteristics of PID are combined with fuzzy tuning gain approach to achieve more acceptable performance. A PID sliding surface is considered such that the robot dynamic equation can be rewritten in terms of sliding surface. Then in order to decrease the reaching time to the sliding surface and deleting the oscillation of the response, a fuzzy tuning system is used for adjusting both controller gains including sliding controller gain parameter and PID coefficient. Controller is applied to two link robot manipulator including model uncertainty and external disturbance as a case study. Simulation study has been done in MATLAB/Simulink environment shows the improvements of the results compare to conventional SMC.**

Keywords: Robotic manipulator, Fuzzy Logic, Manipulator control, Sliding mode control

I. Introduction

The dynamic of robots is described by coupled second nonlinear differential equations and inertial parameter depends on the payload which is often unknown and changes during the task. Usually in a classical control we must have an accurate model, classical control can't compensate accurate model and robust model such as sliding mode control. Although the robustness of the SMC is one of its main characteristics, this is achieved only in sliding phase and the system is sensitive to the structured uncertainty and external disturbances in the reaching phase to the sliding surface. Therefore different approaches for improving the performance of the SMC has been proposed which one of them is intelligent control method such as fuzzy control system [5-7]. The combination of both the approach is considered as a research topic in last few years such that the advantages of both the approaches can be used.[9-13] One simple way to decrease the sensitivity of sliding mode controller to the parametric uncertainty and external disturbances is using high control gain which also decreases the reaching time and tracking error. However high control gain increase the oscillation in the control signal that may lead to the excitation of high frequency unmodeled dynamics which is an undesired phenomenon. To overcome this drawback fuzzy logic can be used for tuning of this gain.

Dhaval Vyas is Assistant Professor with Faculty of Electrical Engineering, L C Institute of Technology, Bhandu, Mahesana, Gujarat, India dhavalforever@gmail.com
Jyoti Ohri is Associate Professor with the Department of Electrical Engineering, National Institute of Technology (NIT), Kurukshetra, India ohrijyoti@rediffmail.com
Ankit Patel is Assistant Professor with Faculty of Electrical Engineering, L C Institute of Technology, Bhandu, Mahesana, Gujarat, India majorankit@gmail.com

II. Robot Manipulator

The dynamics of robot manipulator describes how the robot moves in response to these actuator forces which apply torques at the joint of robot. For simplicity, we will assume that the actuators do not have dynamics of their own and arbitrary torques can be commanded at the joint of the robot.

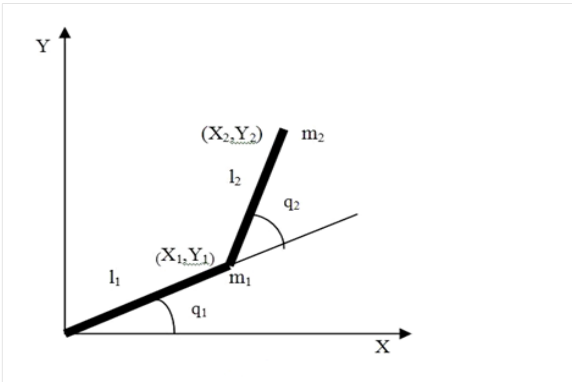

Fig. 1. Two link robot manipulator

Fig.1 shows a two link planner robot arm manipulator. This arm simple enough to simulate, yet has all the nonlinear effects common to general robot manipulators.

To determine the arm dynamics, we assume that the link masses m_1 and m_2 concentrated at the ends of links of lengths l_1 and l_2, respectively. We define the angle of first link q_1 with respect to the inertial frame as depicted in fig.1. The angle of second link q_2 is defined with respect to the orientation of the first link. Torques τ_1 and τ_2 are applied by the actuators to control the angles q_1 and q_2, respectively.

The complete dynamics of two links arm[1] described as,

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

Where the symmetric inertia matrix,

$$M(q)=\begin{bmatrix}\alpha+\beta+2\eta cosq_2 & \beta+\eta cosq_2\\ \beta+\eta cosq_2 & \beta\end{bmatrix} \quad (2)$$

$$C(q,\dot{q})=\begin{bmatrix}-\eta\dot{q}_2 sinq_2 & -\eta(\dot{q}_1+\dot{q}_2)sinq_2\\ \eta\dot{q}_1^2 sinq_2 & 0\end{bmatrix} \quad (3)$$

$$G(q)=\begin{bmatrix}\alpha e_1 cosq_1+\eta e_1 cos(q_1+q_2)\\ \eta e_1 cos(q_1+q_2)\end{bmatrix} \quad (4)$$

$$\left.\begin{aligned}\alpha&=(m_1+m_2l_1^2)\\ \beta&=m_2l_2^2\\ \eta&=m_2l_1l_2\\ e_1&=\frac{g}{l_1}\end{aligned}\right\} \quad (5)$$

This is a special form of state model called "Brunovsky canonical form". Many systems, like the robot arm are naturally in Brunovsky form.

III. Sliding Mode Control With PID

The objective of tracking control is to design a control law for obtaining the suitable input torque τ such the position vector q can track desired trajectory q_d. In this regard, the tracking error vector is defined as (5),

$$e=q_d-q \quad (6)$$

In order to apply the SMC, the sliding surface is considered as the relation (6) which contains the integral part in addition to the derivative term

$$S=\dot{e}+\lambda_1 e+\lambda_2\int_0^t edt \quad (7)$$

Where λ_i is diagonal positive matrix. Therefore s = 0 is a stable sliding surface and $e\longrightarrow 0$ as $t\longrightarrow\infty$. The robot dynamic equation can be rewritten base don sliding surface,

$$M\dot{s}==Cs+f+\tau_d-\tau \quad (8)$$

where,

$$f=M(\ddot{q}_d+\lambda_1\dot{e}+\lambda_2 e)+C(\dot{e}+\lambda_1 e)+\lambda_2\int_0^t edt)+G \quad (9)$$

Now the control input can be considered as below,

$$\tau=\widehat{f}+K_v s+Ksgn(s) \quad (10)$$

where,

$$\widehat{f}=\widehat{M}(\ddot{q}_d+\lambda_1\dot{e}+\lambda_2 e)+\widehat{C}(\dot{e}+\lambda 1_e+\lambda_2\int_0^t edt)+\widehat{G} \quad (11)$$

K are diagonal positive definite matrices and are defined such that the stability conditions are guaranteed.

In order to eliminate the control input chattering problem, the boundary layer is used. The $sgn(\sigma)$ is replaced by $sat(\sigma/\Delta)$ function, where Δ us boundary layer,

TABLE I
Fuzzy Rule Base for Tuning F_{fuzz}

$s/\dot{s}$	NB	NS	Z	PS	PB
N	B	B	M	S	B
Z	B	M	S	M	B
P	B	S	M	B	B

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

where, $\xi=\sigma/\Delta$
By this, there is a boundary layer Δ around the sliding surface such that when the state trajectory reach to this layer will be remaining there [2-4].

IV. Design of Fuzzy SMC PID

As mentioned before, by using high gain in SMC the sensitivity of the controller to the model uncertainty and external disturbances can be reduced. Moreover a high gain in PID part of the control system (K_v) can reduce the reaching time to sliding surface and tracking error [8]. However, increasing the gain causes the increment of the oscillations in the input torque around the sliding surface. Therefore, if this gain can be tuned based on the distance of the states to the sliding surface, a more acceptable performance can be achieved. In other words, the value of gain should be selected high when the state trajectory is far from the sliding surface and when the distance is decreasing, its value should be decreased. This idea can be accomplished by using fuzzy logic in combination with SMC to tune the gain adaptively.

For this purpose, two-input one-output fuzzy system is designed whose inputs are s and $\dot{s}$ which are the distances of the state trajectories to the sliding surface and its derivative, respectively [14-18]. The membership functions of these two inputs are shown in Fig.2 & 3. The output of the fuzzy system is denoted by K_{fuzz} and has been shown in Fig.4. For applying these gains to the control input, the normalization factors N and N_v as the following relations are used

$$K=N\cdot K_{fuzz} \quad (12)$$

$$K_v=N_v\cdot K_{fuzz} \quad (13)$$

This factors can be selected by trial and error such that the stability condition is satisfied.

NB: Negative Big; NS: Negative Small; Z: Zero; PS: Positive Small; PB: Positive Big; M: Medium. For example, when s is negative small (NS) and $\dot{s}$ is positive (P), then K_{fuzz} is small (S).

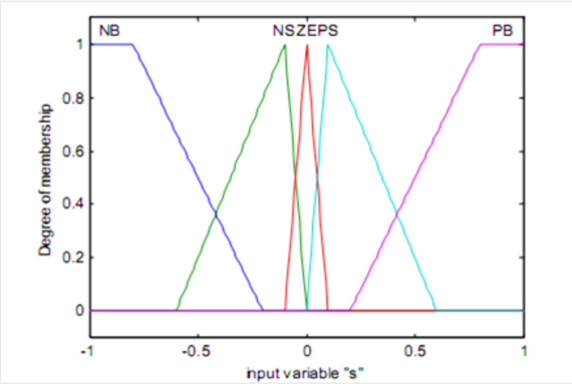

Fig. 2. Input s

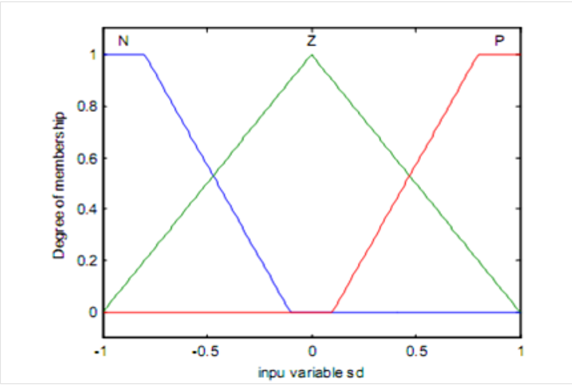

Fig. 3. Input $\dot{s}$

V. Simulation Results

In this section, the simulation results of the proposed controller, which is performed on the model of a two link robotic arm which is given in section 2 are presented. For angle q_1 and q_2 sine and cosine trajectories are chosen respectively. Comparative assessment of both control strategies to the system performance are also discussed in detail.

Using the values given in table.1 simulation is carried out for conventional SMC and Fuzzy SMC-PID controller. Fig.5, 6 & 7 show the trajectory tracking, tracking error and control inputs when system is subjected to conventional SMC. Fig.8, 9 & 10 show the trajectory tracking, tracking error and control inputs when system is subjected to fuzzy SMC-PID for angle q_1 and q_2.

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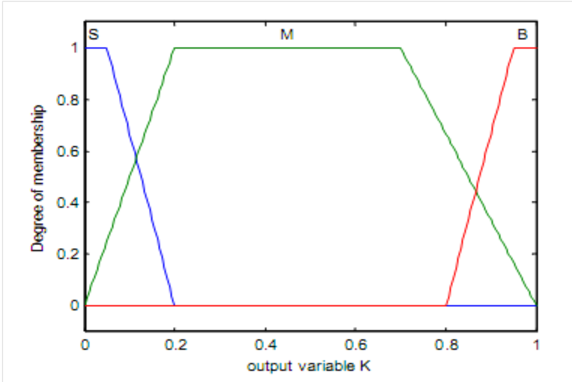

Fig. 4. Output Membership Function

TABLE II
FUZZY RULE BASE FOR TUNING F_{fuzz}

Link Parameter	Without Uncertinity
m_1	0.7 kg
m_2	0.7 kg
l_1	0.7 m
l_2	0.5 m
g	9.81
τ_d	$0.5 sin 2\pi t$
λ_1, λ_2	15, 40
Δ	2
N, N_v	5, 10

VII. Conclusion

In this paper, design of a sliding mode control with a PID loop for robot manipulator was presented in which the gain of both SMC and PID was tuned on-line by using fuzzy approach. The proposed methodology in fact tries to use the advantages of the SMC, PID and Fuzzy controllers simultaneously, i.e the robustness against the model uncertainty and external disturbances, quick response, and on-line automatic gain tuning, respectively. Finally, the simulation results of applying the proposed methodology to a two-link robot were provided and compared with corresponding results of the conventional SMC which show the improvements of results in the case of using the proposed method.

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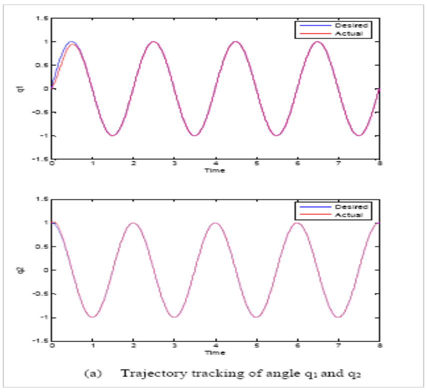

Fig. 5. Trajectory tracking of angle q_1&q_2

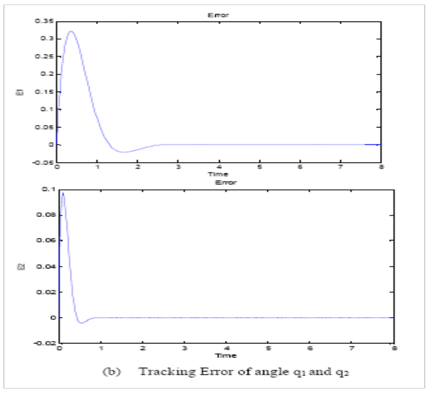

Fig. 6. Trajectory error of angle q_1&q_2

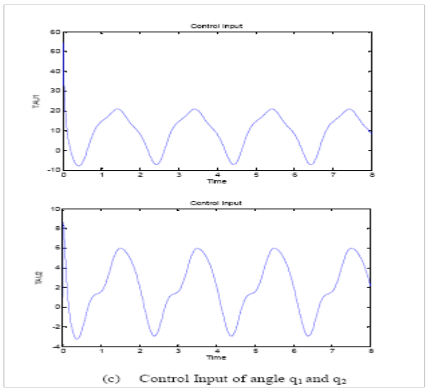

Fig. 7. Control Input of angle q_1&q_2

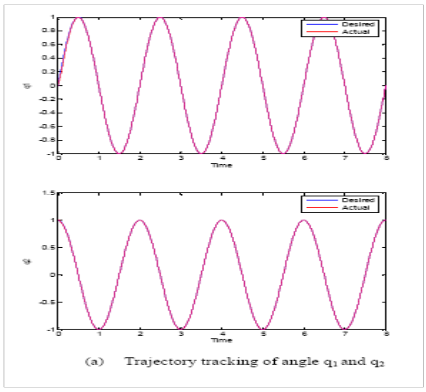

Fig. 8. Trajectory tracking of angle q_1&q_2

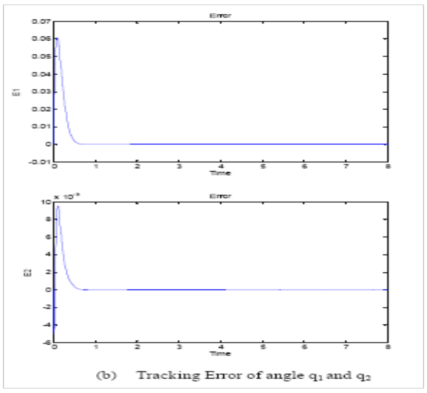

Fig. 9. Trajectory error of angle q_1&q_2

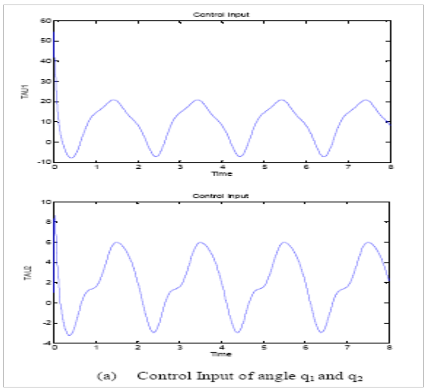

Fig. 10. Control Input of angle q_1&q_2