

Application of Adaptive Robust Control on Robotic Manipulator

Arpit Bubna¹ and Jyoti Ohri²

¹⁻²Dept. of Electrical Engg, National Institute of Technology, Kurukshetra, Haryana
Email: arpit_32014105@nitkkr.ac.in, ohrijyoti@nitkkr.ac.in

Abstract—Robotic manipulator holds very bright future and this system need to be studied extensively. This modern system has increased the growth in field of robotics. In this paper position and velocity tracking of robotic manipulators with system uncertainties is proposed using adaptive sliding mode control. The tracking error can be driven to the desired sliding mode and then asymptotically converge to zero with this control approach. The suggested scheme, in comparison to the robust sliding mode control technique, may overcome system uncertainties without the need for former knowledge. The presented scheme's effectiveness has been shown by theoretical analysis and simulation results are examined.

Index Terms— Sliding Mode Control, Robotic Manipulator, Adaptive Law, Trajectory Tracking, Speed Tracking.

I. INTRODUCTION

Robots have become an integral part of our life. We found ourselves surrounded by a variety of robots. These robots are making our life fast, easy, and comfortable. This comfort is only possible because of the advanced modelling of the system and designing of the advanced controller. This paper talks about one of the complex robotic systems the robotic manipulator. Robotic manipulators have made many academicians interested because of their weight in various areas such as surgical procedures, built-up, mechanization and assembly lines. Intellectuals are working hard to make the services more robust and smart but face discrepancies between the actual plant and the mathematical model developed for controller design in the formulation of any control problem. To achieve good control, these issues must be addressed. Researchers have employed PD control [1], PID control [2], optimum control [3], fuzzy control [4], neural network [5], and other controlling and optimization techniques for the controller to produce the required performance level. As a result, there has been a lot of interest in developing robust control methods to achieve a good performance level. The so-called sliding mode control methodology is one approach to robust controllers. The paper is organized in a section-wise manner. In Section I, brief description of the manipulator and its function is provided. Section II is concerned with the explanation of the controlling tactics used in this paper. Section III and IV show dynamics and mathematical equation of the robotic model. Section V works on controller design. Section VI shows MATLAB simulations on trajectory tracking. Section VII and Section VIII shows the result analysis and conclusion drawn from this paper.

II. CONTROLLING APPROACHES

A. Sliding Mode Control

SMC (Sliding Mode Control) is a unique form of VSC (Variable Structure Control). It is distinguished by a collection of feedback control laws and decision rules. Controllers in SMC are designed to drive and constrain the system states to be in the vicinity of the switching function. This approach has two major advantages. To begin, dynamic behaviour can be tailored by selecting a specific switching function. Second, the closed-loop response loses sensitivity to specific types of uncertainty. The above two benefits make sliding mode control appealing from a design standpoint [6].

B. Adaptive SMC (Sliding Mode Control)

Sliding mode control is an excellent controller, but it requires precision in the dynamic model of the system to provide the required output. In the real world, such conditions are rare; there will always be some level of uncertainty or model variance [7], which may cause difficulties like chattering and hence have an impact on the system's performance. To adapt, an adaptive solution must be used, which has the benefit of not requiring the specific model and so assisting the designer in achieving the required output.

III DYNAMICS OF ROBOTIC MANIPULATOR

Robotic Manipulators are solutions to many problems of modern industries. They can attain high force and productivity even in tough conditions. Let's consider n-joint manipulator as follows[8]:

$$\ddot{l}(q)\ddot{q} + \zeta(q, \dot{q})\dot{q} + G(q) + F(\dot{q}) + \tau_d = \tau$$

Where q is the angle vector, $\ddot{l}(q)$ is the inertia matrix, $\zeta(q, \dot{q})$ shows the centrifugal and coriolis forces, $G(q)$ is the gravity, $F(\dot{q})$ is the frictional force, τ is the control moment and τ_d is the disturbance moment. The above mention equation is known as the dynamic equation of manipulator.

There are a few crucial features to the dynamic equation that one should be aware of.

- The complexity of the above dynamics equation grows as the number of robot joints grows.
- Equation contains high non-linear terms
- ambiguity and time variant nature

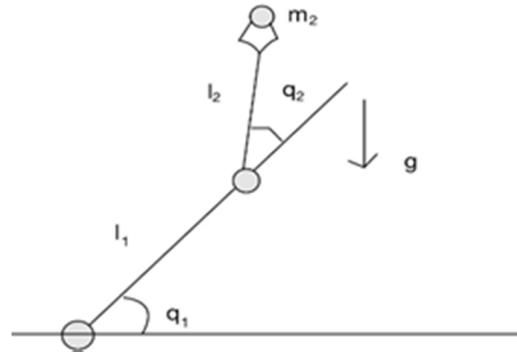


Fig.1 Robotic Manipulator

IV. DESCRIPTION OF MODEL

This section describes the dynamic equation for a two-link robotic manipulator mathematically. The equation is easily obtained by using the lagrangian formulation [9] [10] [11].

$$\frac{d}{dt} \frac{\partial L}{\partial \dot{\theta}} - \frac{\partial L}{\partial \theta} = \tau; \quad q = [q_1 \ q_2]; \quad \tau = [\tau_1 \ \tau_2]$$

Where L defined in terms of kinetic and potential energy

$$L = K(q, \dot{q}) - P(q)$$

With the help of above two equation the dynamic equation can generalized as

$$\ddot{l}(q)\ddot{q} + \zeta(q, \dot{q})\dot{q} + G(q) + F(\dot{q}) + \tau_d = \tau \quad (1)$$

$$\ddot{l}(q) = \frac{\alpha + 2\epsilon\cos(q_2) + 2\eta\sin(q_2)}{\beta + \epsilon\cos(q_2) + \eta\sin(q_2)} \ddot{q}_2 + \frac{\beta + \epsilon\cos(q_2) + \eta\sin(q_2)}{\beta} \ddot{q}_1 \quad (2)$$

$$\zeta(q, \dot{q}) = \begin{pmatrix} (-2\varepsilon \sin(q_2) + 2\eta \cos(q_2))\dot{q}_2 & (-\varepsilon \sin(q_2) + \eta \cos(q_2))\dot{q}_2 \\ (\varepsilon \sin(q_2) - \eta \cos(q_2))\dot{q}_1 & 0 \end{pmatrix} \quad (3)$$

$$G(q) = \begin{pmatrix} \varepsilon e_2 \cos(q_1 + q_2) + \eta e_2 \sin(q_1 + q_2) + (\alpha - \beta + e_1)e_2 \cos(q_1) \\ \varepsilon e_2 \cos(q_1 + q_2) + \eta e_2 \sin(q_1 + q_2) \end{pmatrix} \quad (4)$$

Where $\alpha, \beta, \varepsilon, \eta$ are constant,

$$\alpha = I_1 + m_1 l_{c1}^2 + I_e + m_e l_{ce}^2 + m_e l_1^2$$

$$\beta = I_e + m_e l_{ce}^2$$

$$\varepsilon = m_e l_1 l_{ce} \cos(\delta_e)$$

$$\eta = m_e l_1 l_{ce} \sin(\delta_e)$$

TABLE I. VALUE OF SYSTEM PARAMETERS

m_1	l_1	l_{c1}	I_1	m_e	l_{ce}	I_e	δ_e	e_1	e_2
1	1	0.5	1/12	3	1	2/5	0	-7/12	9.81

V. CONTROLLER DESIGN

A Sliding mode controller

Generalized dynamic equation of robotic manipulator is as follows

$$\ddot{q}(q) + \zeta(q, \dot{q})\dot{q} + G(q) + F(\dot{q}) + \tau_d = \tau \quad (5)$$

Each expression in the equation has already been alerted.

Our goal is to provide a sliding mode control for robotic manipulator position and speed tracking. Our system model does not have good exactness and is affected by parameter change during the designing of controller, so the output obtained from the plant will be inappropriate. If $q_d(t)$ is the reference signal and $q(t)$ being the output from the plant. The tracking error [10]

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

$$\dot{e}(t) = \dot{q}_d(t) - \dot{q}(t) \quad (7)$$

$$\dot{q}_r = \dot{q}_d - \Lambda e(t) \quad (8)$$

$$\ddot{q}_r = \ddot{q}_d - \Lambda \dot{e}(t) \quad (9)$$

The sliding variable as:

$$s = \dot{e} + \Lambda e$$

$$\text{Where } \Lambda = \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} \quad \lambda_i > 0, i = 1, 2$$

$$\tau = \ddot{q}(q)\ddot{q}_r + \zeta(q, \dot{q})\dot{q}_r + G(q) + K_d s + \varepsilon \text{sgns} \quad (\text{Control law}) \quad (10)$$

$$K_d = \begin{bmatrix} k_{d1} & 0 \\ 0 & k_{d2} \end{bmatrix} \quad (11)$$

B. Adaptive Sliding Mode Control

Our goal is to create a controller for position and speed tracking while keeping in mind that there is no realistic model of the system. The value of parameters is changed in real time according to adaptive rules with the purpose of guiding the nonlinear system's output to follow a specified trajectory, which can approximate the systems unknown.

As studied in adaptive sliding mode controller design method for robotic manipulator the system parameters are the unknown[7].

The controller is designed as:

$$\tau = \hat{\ddot{q}}(q)\ddot{q}_r + \hat{\zeta}(q, \dot{q})\dot{q}_r + \hat{G}(q) + K_d s + \varepsilon \text{sgns} \quad (12)$$

The adaptive law used:

$$\dot{\hat{\alpha}} = -\eta \alpha^T s \quad (13)$$

VI. MATLAB ANALYSIS

A. Sliding Mode control

In this section, the robotic manipulator dynamic model is not precise so the controller does not perform very well and thus does not provide good tracking performance.

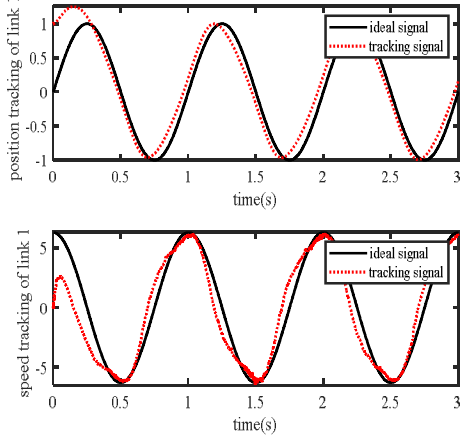


Fig 2 Position and Speed tracking of Link 1 Under SMC

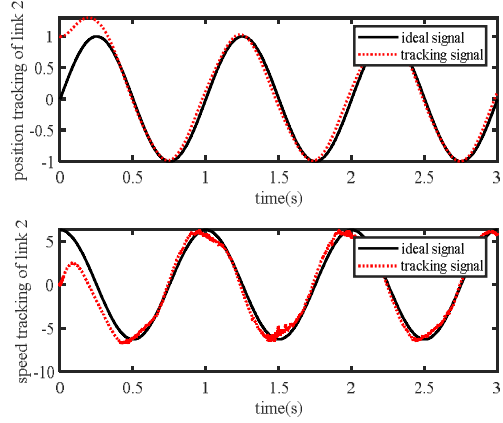


Fig 3 Position and Speed tracking of Link 2 under SMC

B. Adaptive SMC

The correct model of a robotic manipulator is not provided in this area, and the system is subject to uncertainty and parameter change. The system employs adaptive SMC to deal with it. Even when subjected to such conditions, the simulation demonstrates a significant improvement in the system's performance.

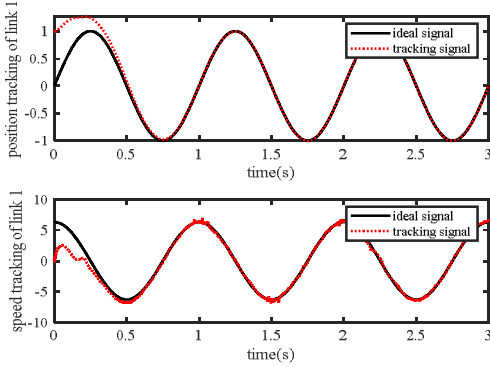


Fig 4 Position and Speed tracking of Link 1 Under Adaptive SMC

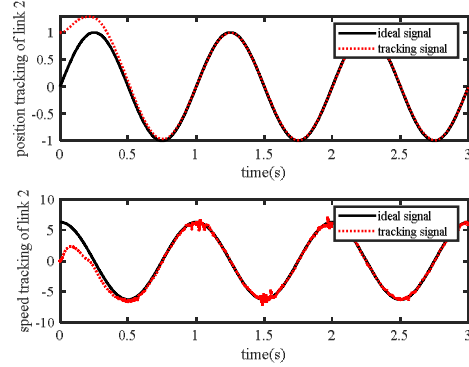


Fig 5 Position and Speed tracking of Link 2 under Adaptive SMC

VII. RESULT ANALYSIS

From the above MATLAB simulations, various analyses can be done, I in this paper focuses on error analysis of position and velocity obtained from using SMC and Adaptive SMC controller.

TABLE II. 2-NORM ERROR OF LINKS (POSITION)

Position	Position of Link 1 (SMC with uncertainty)	Position of Link 2 (SMC with uncertainty)	Position of Link 1 (Adaptive SMC with uncertainty)	Position of Link 2 (Adaptive SMC with uncertainty)
2-norm of Error	74.005	71.97	68.12	68.05

TABLE III. 2-NORM ERROR OF LINKS (VELOCITY)

Velocity	Velocity of Link 1 (SMC with uncertainty)	Velocity of Link 2 (SMC with uncertainty)	Velocity of Link 1 (Adaptive SMC with uncertainty)	Velocity of Link 2 (Adaptive SMC with uncertainty)
2-norm of Error	443.13	446.93	416.9	427.95

From the above table one can easily get know that norm 2 of error decreased in both cases (position and velocity). The adaptive control acted superior in spite of facing model ambiguity.

VIII. CONCLUSIONS

Sliding mode control (SMC) and adaptive SMC are nonlinear control techniques that have excellent correctness, toughness, and execution simplicity. This paper focuses on figuring out how to better adapt sliding mode control to modern control tactics where exact modeling is a cumbersome task. When exact modeling of the system is available, sliding is better fit, but when subjected to undesirable noise and model ambiguity, it loses its capacity to maintain the intended output. This flaw can be easily remedied by combining adaptive control, which decreases the influence and hence results in better output (chattering, location tracking, and speed tracking). This research paper with simulation illustrates how adaptive SMC outperforms conventional SMC. The tables (II & III) shown in this paper gives a comparative analysis of error in position and velocity tracking when both control methodology is used.

REFERENCES

- [1] L. Fan and E. M. Joo, "Linear and nonlinear PD-type control of robotic manipulators for trajectory tracking," *2009 4th IEEE Conf. Ind. Electron. Appl. ICIEA 2009*, pp. 3442–3447, 2009, doi: 10.1109/ICIEA.2009.5138846.
- [2] S. Singh, M. S. Qureshi, and P. Swarnkar, "Comparison of conventional PID controller with sliding mode controller for a 2-link robotic manipulator," *Int. Conf. Electr. Power Energy Syst. ICEPES 2016*, no. 3, pp. 115–119, 2017, doi: 10.1109/ICEPES.2016.7915916.
- [3] W. Boukadida, R. Bkekri, A. Benamor, and H. Messaoud, "Trajectory tracking of robotic manipulators using optimal sliding mode control," *2017 Int. Conf. Control. Autom. Diagnosis, ICCAD 2017*, vol. 21, no. 2, pp. 545–550, 2017, doi: 10.1109/CADIAG.2017.8075717.
- [4] M. Manjeet and S. Sathans, "Fuzzy based control of two link robotic manipulator and comparative Analysis," *Proc. - 2013 Int. Conf. Commun. Syst. Netw. Technol. CSNT 2013*, no. 2, pp. 562–567, 2013, doi: 10.1109/CSNT.2013.121.
- [5] B. Jin, "Robotic manipulator trajectory control using neural networks," *Proc. Int. Jt. Conf. Neural Networks*, vol. 2, no. 1, pp. 1793–1796, 1993, doi: 10.1109/ijcnn.1993.717002.
- [6] Bartoszewicz and J. Zuk, "Sliding mode control - Basic concepts and current trends," *IEEE Int. Symp. Ind. Electron.*, no. 1, pp. 3772–3777, 2010, doi: 10.1109/ISIE.2010.5637990.
- [7] D. Zhao, Q. Cao, S. Li, and Q. Zhu, "Adaptive full-order sliding mode control of rigid robotic manipulators," *Chinese Control Conf. CCC*, vol. 2015-Sept, pp. 657–662, 2015, doi: 10.1109/ChiCC.2015.7259713.
- [8] T. C. Kuo, Y. J. Huang, and B. W. Hong, "Design of adaptive sliding mode controller for robotic manipulators tracking control," *World Acad. Sci. Eng. Technol.*, vol. 77, no. 5, pp. 190–194, 2011.
- [9] Gopal, *Digital control and state variable methods*, 4th ed. New Delhi: Tata McGraw Hill Education Pte. Ltd., 2014.
- [10] J.-J. E. Slotine and L. Weiping, *Applied nonlinear control: International edition*. Upper Saddle River, NJ: Pearson, 1990.
- [11] Jinkun and W. Xinhua, *Advanced sliding mode control for mechanical systems: Design, analysis and MATLAB simulation.*, 2012.