

Comparison of Conventional PID Controller with Sliding Mode Controller for a 2-Link Robotic Manipulator

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Abstract: Considering the increase in application of robotic manipulators in various dimensions, trajectory tracking has become one of the important aspects for controllers. This paper depicts a comparison between the conventional PID controller and sliding mode controller (SMC) for a double link robotic manipulator. The paper adheres to the problem of modelling and controller design keeping the non-linearity associated with robotic manipulator in mind. The aim of this paper is to examine which controller is more robust for trajectory tracking. Simulation is carried out in MATLAB and the system output is plotted against the reference input to record the tracking performance.

Keywords- Two Link Robotic Arm, PID, SMC, Lyapunov stability criteria

I. INTRODUCTION

The non-linear and complicated dynamics of robotic arm with the aspect that few quantities are uncertain in the system (parameter disturbance, unknown joint friction, inertia, different payloads and external perturbations) makes it inconvenient to design a potential controller for the same. These non-linearity's and uncertainties results in poor tracking performance of robotic manipulator [1].

There are a number of control strategies that can be used for controlling of robotic manipulator [2-3]. The most common and simple strategy among them is PID controller. But a classical control method requires an exact model of the plant, so it cannot compensate for the robustness provided by the adaptive control schemes [4]. One such robust control scheme based on variable structure is sliding mode control (SMC) technique [5].

SMC is a non-linear, robust technique that is well suited for the controlling of robotic arm [6]. The controller is independent of model uncertainties and parameter variations if any, moreover this controller does not demand for an exact model of the robotic arm, therefore a preferred choice [7]. One more advantage of SMC is we can obtain sliding mode motion for higher order systems if the controller is designed via reduced order modeling [8]. During sliding mode the plant is compelled to slide on or near the sliding surface[9]. The only

problem faced by classical SMC is a phenomenon called chattering, which is a high frequency disturbance of controller output. But this phenomenon can be easily avoided by using a smooth function like saturation function rather than using sign function

This paper is organized in the following manner: In section II, dynamic articulation of robotic arm is introduced. The state model is represented in a common form known as “Brunovsky canonical form”. The III section discusses the designing of controllers PID and SMC respectively. In section IV, the simulation results are presented and discussed and finally in section V, the conclusion is drawn.

II. MATHEMATICAL MODELLING OF ROBOTIC MANIPULATOR

Consider the dynamics of two link manipulator derived via Lagrange's equation of motion [1] –

$$\frac{d}{dt} \frac{\partial L}{\partial \dot{\theta}} - \frac{\partial L}{\partial \theta} = \tau ; \theta = [\theta_1 \theta_2]^T ; \tau = [\tau_1 \tau_2]^T \quad (1)$$

The kinetic energy K and the potential energy P are combined to give the Lagrangian L –

$$L = K(\theta, \dot{\theta}) - P(\theta) \quad (2)$$

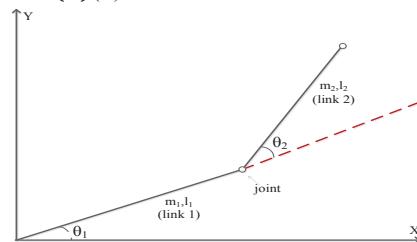


Fig 1. Two link robotic manipulator
The manipulator dynamics of double link manipulator [7]

$$M(\theta)\ddot{\theta} + V(\theta, \dot{\theta}) + G(\theta) = \tau \quad (3)$$

Where

Inertia matrix, $M(\theta) =$

$$\begin{bmatrix} \beta l_1^2 + m_2 l_2^2 + 2m_2 l_1 l_2 \cos\theta_2 + J_1 & m_2 l_2^2 + m_2 l_1 l_2 \cos\theta_2 \\ m_2 l_2^2 + m_2 l_1 l_2 \cos\theta_2 & m_2 l_2^2 + J_2 \end{bmatrix} \quad (4)$$

Nonlinear matrix, $V(\theta, \dot{\theta}) =$

$$\begin{bmatrix} -m_2 l_1 l_2 (2\dot{\theta}_1 \dot{\theta}_2 + \dot{\theta}_2^2) \sin\theta_2 \\ m_2 l_1 l_2 \dot{\theta}_1^2 \sin\theta_2 \end{bmatrix} \quad (5)$$

and Gravity matrix, $G(\theta) =$

$$\begin{bmatrix} \beta g l_1 \cos\theta_1 + m_2 g l_2 \cos(\theta_1 + \theta_2) \\ m_2 g l_2 \cos(\theta_1 + \theta_2) \end{bmatrix} \quad (6)$$

where $\beta = (m_1 + m_2)$

III. DESIGNING OF CONTROLLERS

A. PID CONTROLLER

The simplest technique for the motion control of robotic manipulator is PID controller. The controller gains K_p, K_i, K_d once tuned are fixed. The value of these gains is obtained either by manual tuning or by some proven methods like Zeigler Nichols, TyreusLuyben etc. The control law for PID is given by –

$$u = K_p e(t) + K_d \frac{de(t)}{dt} + K_i \int e(t) dt \quad (7)$$

where, $e(t) = \theta_d(t) - \theta(t)$ is the tracking error signal

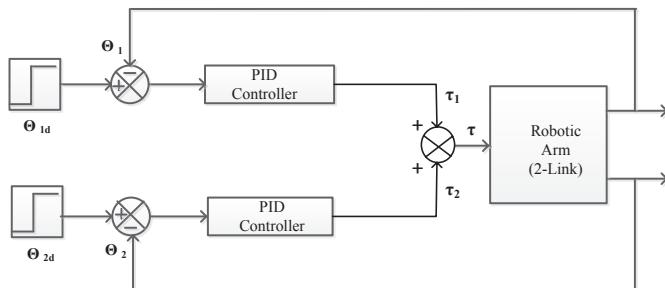


Fig. 2 Block diagram of PID controller 2 link for robotic arm

B. SLIDING MODE CONTROLLER

This is one of the most powerful technique for the controlling of non-linear systems when it comes to precision and robustness. The implementation of SMC consist of two stages-

- Sliding or switching surface design so that the plant trajectory anywhere in the plane is driventowards the switching surface in finite time.
- To design a controller so that the plant trajectory remains attractive to switching surface.

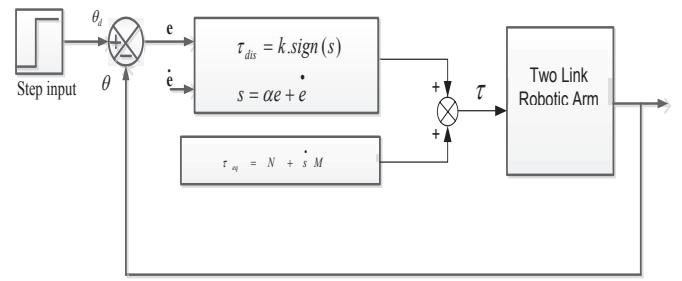


Fig. 3 Block diagram of sliding mode for a 2-link robotic arm

A linear sliding surface is used in this paper,given by-

$$s = \alpha e + \dot{e} = 0 \quad (8)$$

$$\text{So, } \dot{s} = \alpha \dot{e} + \ddot{e} \quad (9)$$

Where s is sliding surface parameter, $\alpha \in R^+$ and tracking error,

$$e = \theta_d - \theta \quad (10)$$

From equation (3)

$$\ddot{\theta} = M^{-1}(\theta)\{\tau - [V(\theta, \dot{\theta}) + G(\theta)]\} \quad (11)$$

$$K = \tau - [V(\theta, \dot{\theta}) + G(\theta)] \quad (12)$$

So,

$$\ddot{\theta} = M^{-1}(\theta)K \quad (13)$$

From equation (8) and (9)

$$\dot{s} = \alpha(\dot{\theta}_d - \dot{\theta}) + (\ddot{\theta}_d - \ddot{\theta}) \quad (11)$$

$$\dot{s} = \alpha(\dot{\theta}_d - \dot{\theta}) + (\ddot{\theta}_d - M^{-1}(\theta)K) \quad (12)$$

The total torque required by the robotic manipulator is-

$$\tau = \tau_{eq} + \tau_{dis} \quad (13)$$

The equivalent torque makes the derivative of switching surface equal to zero and is given by –

$$\tau_{eq} = [M^{-1}(V + G) + \dot{s}]M \quad (14)$$

While the discontinuous or corrective torque compensates for any deviation from the switching surface and is given by -

$$\tau_{dis} = K.sgn(s) \quad (15)$$

where the sliding function $sgn(s)$ is –

$$sgn(s) = \begin{cases} 1 & s > 0 \\ -1 & s < 0 \\ 0 & s = 0 \end{cases} \quad (16)$$

and K is a positive constant.

Therefore the total driving force or torque is computed as –
 $\tau = (V + G) + \dot{s} \cdot M + K \cdot sgn(s)$ (17)

Let the Lyapunov function candidate be –

$$V = \frac{1}{2} s^2 \quad (18)$$

The Lyapunov stability criteria for the designing of controller is-

$$\dot{V} = s\dot{s} < 0 \quad (19)$$

The condition to be satisfied for the proper working of controller so that it tracks the reference signal is-

$$M^{-1}(\theta)K \cdot sgn(s) > \ddot{\theta} \quad (20)$$

IV. RESULTS AND DISCUSSION

This section discusses the simulation results of both PID and SMC controller which are subjected to step input. The first and second joint of robotic manipulator is moved from initial (zero) to final (reference step) position. The reference value of both the angles is 4 rad and 1 rad respectively. The best possible values of tuning parameters for SMC are $\alpha_1 = 3, \alpha_2 = 2.5, K_1 = 20, K_2 = 10$ which are also shown in table 1. The table 2 gives the value of steady state errors for PID and SMC controller with and without disturbance.

Figure 4 and 5 shows the tracking performance of two joint angles namely theta1 and theta2 with PID and figure 6 and 7 shows performance with SMC. The next four figures 8, 9, 10 and 11 show the tracking performance of PID and SMC controller when subjected to disturbance. For both the controllers the disturbance is created by an impulse function. The results show that PID controller works best in ideal conditions but when the robotic arm is subjected to disturbance SMC proves to be robust as the results remain unchanged with slight disturbance at the reference value. This disturbance is known a chattering and can be avoided by the use of smooth saturation function instead of signum function.

The tables 3 and 4 depicts the performance evaluation of both the controllers. The overshoot in case of PID controller is large which will affect the system performance and mechanical parts in long run.

Table 1: Tuning Parameters

Angle	θ_1 (4 rad)		θ_2 (1 rad)	
Parameters →	α_1	K_1	α_2	k_2
Data	3	20	2.5	10

Table 2: Steady State errors with PID and SMC

Controller	PID		SMC	
Error →	ss error ₁	Ss error ₂	sserror ₁	ss error ₂
with disturbance	- 0.0818 5	0.037	0.03393	0.0036
without disturbance	0.0935	-0.0062	0.007694	0.0004 82

Table 3: Performance values of θ_1 and θ_2 without disturbance

Controller	PID		SMC	
Performance index ↓	θ_1	θ_2	θ_1	θ_2
Rise time (T_r)	0.269 s	0.116s	1.2s	1.7s
Settling time (T_s)	5.26s	2.13s	3.1s	3.2s
Peak overshoot(M_p)	14.9 %	14%	0	0
Peak	4.6	1.14	4	1

Table 4: Performance values of θ_1 and θ_2 with disturbance

Controller	PID		SMC	
Performance index ↓	θ_1	θ_2	θ_1	θ_2
Rise time (T_r)	0.304s	0.069s	1.2s	1.7s
Settling time (T_s)	6.43s	1.44s	3.4s	3.9s
Peak overshoot(M_p)	14.2%	14.7%	0	0
Peak	4.7	1.15	4	1

A) PID and SMC controller without disturbance

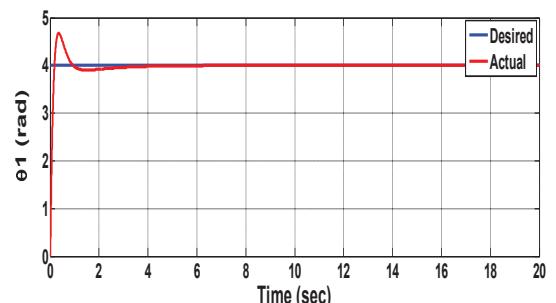


Fig. 4 Trajectory tracking of θ_1 with PID

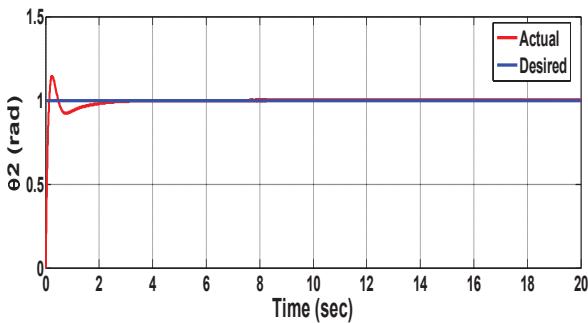


Fig. 5 Trajectory tracking of θ_2 with PID

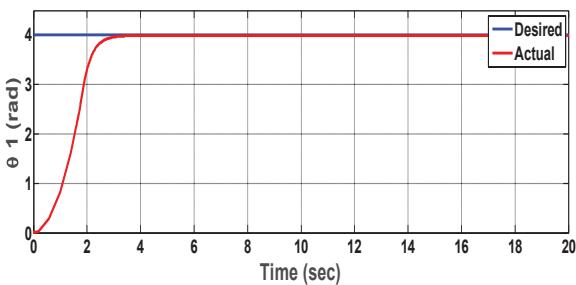


Fig. 6 Trajectory tracking of θ_1 with SMC

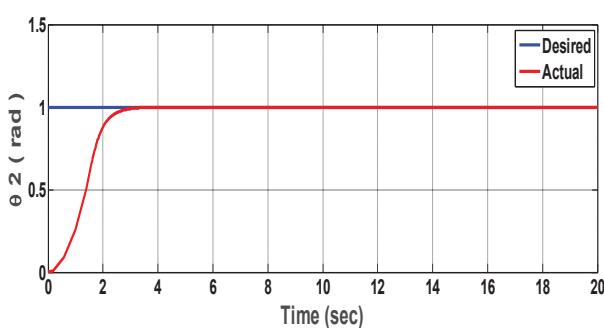


Fig. 7 Trajectory tracking of θ_2 with SMC

B) PID and SMC controller with disturbance

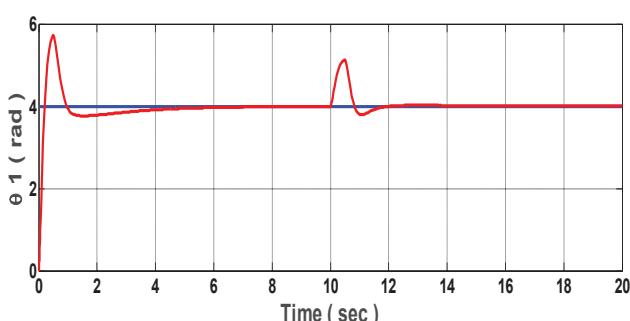


Fig. 8 Trajectory tracking of θ_1 with disturbance for PID

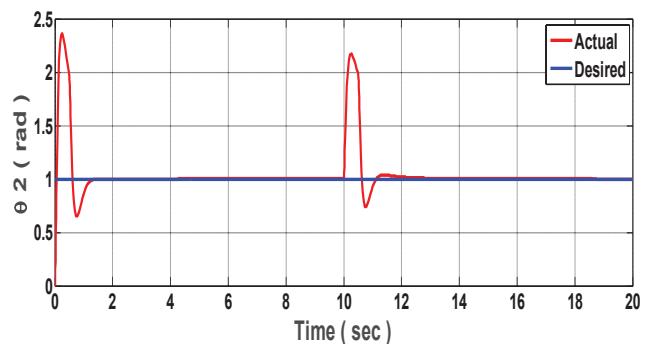


Fig. 9 trajectory tracking of θ_2 with disturbance for PID

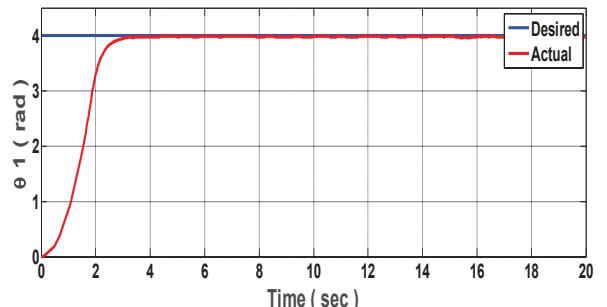


Fig. 10 Trajectory tracking of θ_1 with disturbance SMC

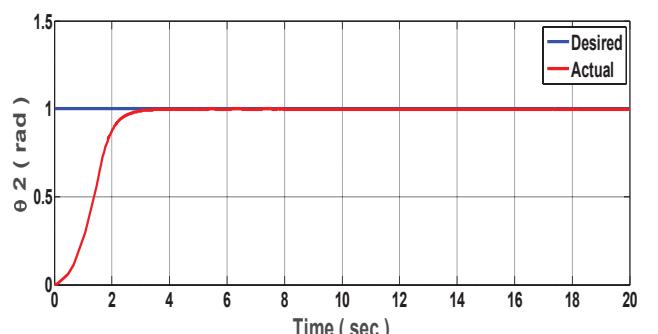


Fig. 11 Trajectory tracking of θ_2 with disturbance SMC

V. CONCLUSION

The paper presents modelling, designing and simulation of double link robotic manipulator with two types of controller. Both the controllers conventional PID and SMC are implemented on robotic arm successfully. The simulation is carried out in MATLAB/SIMULINK environment. The results show that both the controllers give good tracking performance of the robotic arm. However it can be seen from the results that the settling time for SMC is better than PID controller i.e. the arm tracks the input faster in case of SMC. The problem of chattering is removed by replacing sign function with saturation function. The value of different parameters used in modelling are provided in table 5.

Table 5: APPENDIX

Parameters	Values
m_1	0.5
m_2	1.5
l_1	0.8
l_2	1
J_1	5
J_2	5

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