Adaptive Sliding Mode Control of PUMA 560 Robotic ARM

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Abstract **-Adaptive sliding mode control has been successfully applied to the PUMA robotic arm. Nowadays robots are integral part many industrial applications. Hence control of these plays crucial role. PUMA robots are well known and in this present work, adaptive sliding mode control is used to control the position. The efficacy of the presented controller has been validated using MATLAB simulations.**

Keywords – PUMA – robot – adaptive sliding mode control.

I. INTRODUCTION

Programmable Universal Machine for Assembly (PUMA) was well known for its robotics. The PUMAs were the most popular robots of last decades of twentieth century. The design of such robots was classified into three categories viz., 200 series, 500 series and 700 series. The 200 series comprises of smaller units of desktop size. The 500 series were designed to reach a height of 2 meters and were the most popular ones. The last one among these categories is 700 series which were developed for carrying out works such as paint, welding, assembly line etc. One common thing for all these categories is that the design contains two parts: (i) the mechanical arm and (ii) the control system. These two parts are generally interconnected by two multi-conductor cables where in one cable supplies power to the servo motors and brakes and the second one exercises feedback positioning for each joint of the assembly.

II. MODELING OF PUMA ROBOTIC ARM

The general for of 6-DOF (Degrees of freedom) configuration equation is only utilized in the present work to make into a 3-DOF robot. Here, the lass three joints were kept blocked i.e., the initial states of these joints were assigned zero, however the robot will be moving. This leads to formation of equations for the kinematics of 3-DOF robot which permit us to define a new D-H coordinate system that can be implemented. Here a homogenous transformation matrix relating the 3^{rd} coordinate frame to the first coordinate frame is developed. However, the 3-DOF PUMA will have the same kinematics of its 6-DOF convenient with q_4, q_5 and q_6 set to zero. The following set of equations is considered (1). The robotic arm is shown in Fig.1.

“For the configuration space equation of the robot

$$\Gamma = A(q).\ddot{q} + B(q).\dot{q}\dot{q} + C(q).\dot{q}^2 + g(q)$$

We set $q_4 = q_5 = q_6 = 0$, this yields

$$\ddot{q} = \left[\ddot{q}_1 \ldots \ddot{q}_2 \ldots \ddot{q}_3 \ldots 0 \ldots 0 \ldots 0 \quad\right]^T ,$$

$$\left[\dot{q}\dot{q}\right] = \left[\dot{q}_1\dot{q}_2 \ldots \dot{q}_1\dot{q}_3 \ldots 0 \ldots 0 \ldots 0 \ldots \dot{q}_2\dot{q}_3 \ldots 0 \ldots 0 \ldots 0 \ldots 0 \ldots 0 \ldots 0 \ldots 0 \ldots 0\right]^T ,$$

$$\left[\dot{q}^2\right] = \left[\dot{q}_1^{\,2} \ldots \dot{q}_2^{\,2} \ldots \dot{q}_3^{\,2} \ldots 0 \ldots 0 \ldots 0\right]^T ,$$

$$B(q).\dot{q}\dot{q} = \left[b_{112}.\dot{q}_1\dot{q}_2 + b_{113}.\dot{q}_1\dot{q}_3 + b_{123}.\dot{q}_2\dot{q}_3 \ldots b_{223}.\dot{q}_2\dot{q}_3 \ldots 0 \ldots b_{412}.\dot{q}_1\dot{q}_2 + b_{413}.\dot{q}_1\dot{q}_3 \ldots 0 \ldots 0\right]^T \text{ and}$$

$$C(q).\dot{q}^2 = \left[c_{12}.\dot{q}_2^{\,2} + c_{13}.\dot{q}_3^{\,2} \ldots c_{21}.\dot{q}_1^{\,2} + c_{23}.\dot{q}_3^{\,2} \ldots c_{31}.\dot{q}_1^{\,2} + c_{32}.\dot{q}_2^{\,2} \ldots 0 \ldots c_{51}.\dot{q}_1^{\,2} + c_{52}.\dot{q}_2^{\,2} \ldots 0\right]^T$$

The angular acceleration is found as to be

$$\ddot{q} = A^{-1}(q).\left\{\Gamma - \left[B(q).\dot{q}\dot{q} + C(q).\dot{q}^2 + g(q)\right]\right\}$$

Now let $I = \left\{\Gamma - \left[B(q).\dot{q}\dot{q} + C(q).\dot{q}^2 + g(q)\right]\right\} \Rightarrow \ddot{q} = A^{-1}(q).I$

$$I_1 = \Gamma_1 - \left[b_{112}.\dot{q}_1\dot{q}_2 + b_{113}.\dot{q}_1\dot{q}_3 + b_{123}.\dot{q}_2\dot{q}_3\right] - \left[c_{12}.\dot{q}_2^{\,2} + c_{13}.\dot{q}_3^{\,2}\right]$$

$$I_2 = \Gamma_2 - \left[b_{223}.\dot{q}_2\dot{q}_3\right] - \left[c_{21}.\dot{q}_1^{\,2} + c_{23}.\dot{q}_3^{\,2}\right] - g_2$$

$$I_3 = \Gamma_3 - \left[c_{31}.\dot{q}_1^{\ 2} + c_{32}.\dot{q}_2^{\ 2}\right] - g_3$$
$$I_4 = \Gamma_4 - \left[b_{412}.\dot{q}_1\dot{q}_2 + b_{413}.\dot{q}_1\dot{q}_3\right]$$
$$I_5 = \Gamma_5 - \left[c_{51}.\dot{q}_1^{\ 2} + c_{52}.\dot{q}_2^{\ 2}\right] - g_5$$
$$I_6 = \Gamma_6$$

These equations tell us that in order to ensure that $\ddot{q}_4, \ddot{q}_5$ and $\ddot{q}_6$ keep their zero values, it is better to set $I_4 = I_5 = I_6 = 0$; so by holding the control torques of the last three joints as

$$\Gamma_4 = \left[b_{412}.\dot{q}_1\dot{q}_2 + b_{413}.\dot{q}_1\dot{q}_3\right]$$

$\Gamma_5 = \left[c_{51}.\dot{q}_1^{\ 2} + c_{52}.\dot{q}_2^{\ 2}\right] + g_5$ and $\Gamma_6 = 0$, the last three joints are blocked at their initial states.”

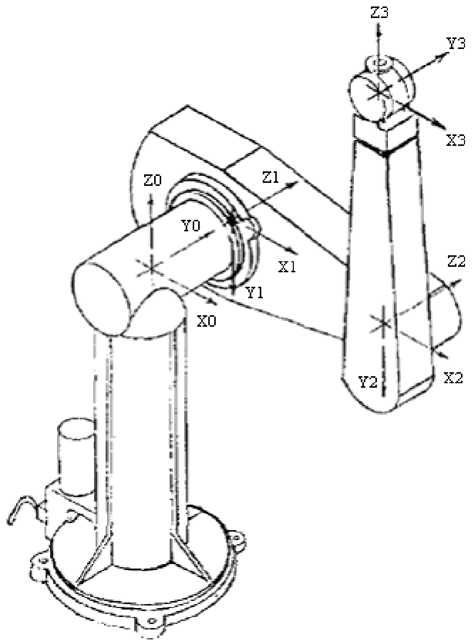

Fig.1. Robotic Arm

III. ADAPTIVE SLIDING MODE CONTROL

The following nonlinear system with uncertainties is considered.

$$\frac{dx}{dt} = f(x) + g(x) * u \qquad (1)$$

Here u and x are control input and state vector respectively

The dynamics of the sliding variable s(x,t) are given in equation (2)

$$\dot{s} = \frac{\partial s}{\partial x}\dot{x} + \frac{\partial s}{\partial t} \qquad (2)$$

Let us demonstrate a new adaptive sliding mode controller $u(s,t)$ with the same features as classical SMC such as robustness and finite time convergence. The sliding variable dynamics in equation (2) is controlled by equation (3)

$$u = -K(t)\mathrm{sign}(s(x,t)) \qquad (3)$$

The adaptive law is provided as equation (4)

$$\dot{K} = \bar{K}\,|(s(x,t)| \qquad (4)$$

Here $K > 0$ and $\bar{K} > 0$ and sliding mode is established in a finite time.

IV. SIMULATION RESULTS

The results obtained by running the above program using MATLAB and the results are shown presented in Figs.2 to 4. One can observe from Fig.2 that the target position was reached by the robot arm after 2 seconds. However, with respect to other two arms as illustrated by Figs. 3 and 4 the arm reached the target position instantaneously indicating that the present model work well for PUMA robot with 3-DOF. Further one can notice that the three arm positions were very well in reaching the target in a short while. This means that the said model can be implemented successfully for many robotic applications.

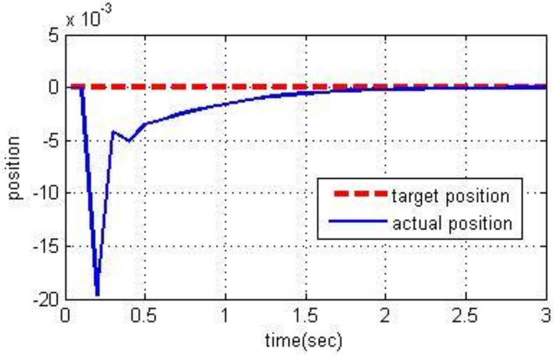

Fig.2 Theta_1 of robotic arm

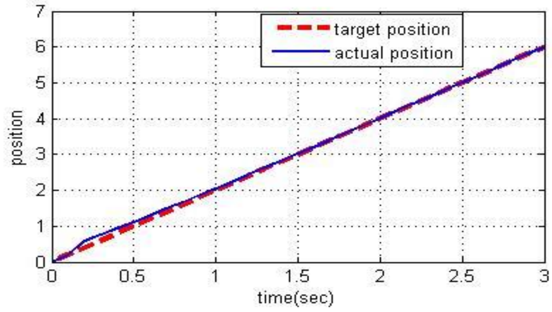

Fig.3 Theta_2 of robotic arm

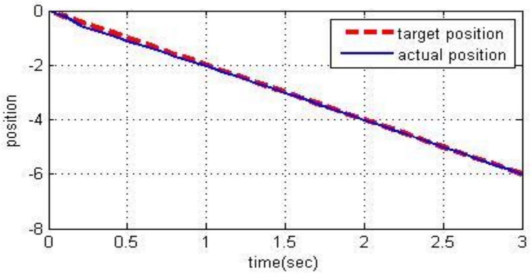

Fig.4. Theta_3 of robotic arm

V. CONCLUSION

In order to control the PUMA robotic arm, in the present investigation an adaptive sliding mode control has been successfully implemented. The efficacy of the presented controller has been validated using MATLAB simulations. The results showed that the performance of controller is superior for the robotic arm control.

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