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Sliding Mode Control of a Two-link Robot Manipulator Using Adams & Matlab Software

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Abstract—**This paper presents the design of a sliding mode controller (SMC) for trajectory tracking problem for a two-link planar robot manipulator. A virtual prototype of the manipulator has been built by using Adams software. Also, the controller works is achieved in Matlab/Simulink software. The system is simulated in both Matlab and Adams software together which is called co-simulation. The manipulator system has two inputs (torques of actuators) and four outputs (angle of 1st joint, angle of 2nd joint and x-y components of end effector position). The sliding mode controller (SMC) is designed with the constant variation reaching law. The simulation results show that the sliding mode controller (SMC) can successfully achieve trajectory tracking of a two-link planar robot manipulator according to the desired trajectory.**

Keywords—sliding mode control, two-link robot, robot manipulators, trajectory tracking, adams, matlab

I. INTRODUCTION

The robot manipulators are commonly used in the industrial applications such as material handling works, continuous manufacturing systems, assembly lines, welding operations etc. The manipulators usually consist of rigid links are connected each other by the joints that allow motion of the neighboring links. The advantages of the planar robot manipulators are their high mobility and larger working area than other robot manipulator structures [1]. In the literature, the robot manipulators with two or three degrees of freedom are mostly used [2-3]. Also, the manipulators with four or more degrees of freedom are available in [4]. However, because of their complex dynamics and kinematics calculations, they have few widespread usages. Adams is software to build and simulate multi-body dynamics of platforms. Here, the virtual models are used to achieve desired layout of dynamic systems. Our former research which provided a background of the improving this paper presents development of a multi-body simulation model using by Adams software [5].

For many years, the problem of trajectory tracking control of robot manipulators has been discussed by researchers [6-7]. To deal with the trajectory tracking, the researchers have focused on the studies about the controller design such as fuzzy neural network [8], the PID [9], the SMC [10-11], the adaptive control [12-13], the time-delay control [14].

The sliding mode controller (SMC) was first introduced in the Soviet Union in the late 1950s and the first work on it was made by Emelyanov in early 1960s. In the 1977, Utkin's English books and articles were announced to the whole world. A new control approach with sliding mode was introduced by Utkin in 1992. Then the control strategy for linear and nonlinear systems, the different switching mechanisms and the creation of simple sliding-mode control rules are studied in [15-17]. The sliding mode controller has insensible feature against to errors in the modeling, the parametric change of the system and the external disturbing effects. Moreover, the SMC controller has many advantages such as robustness, stability, fast response, good transient performance [18].

This paper aims designing of a sliding mode controller (SMC) for trajectory tracking problem for a two-link planar robot manipulator. The numerical model of the system is modelled in Adams software according to the desired control loop. The Adams model has two inputs (torques of actuators) and four outputs (angle of 1st joint, angle of 2nd joint and x-y components of end effector position). The inverse kinematic equations of the planar manipulator are manually calculated. The reference angles of the joints are obtained to use as desired reference of the control loop. The sliding mode controller is designed and implemented for the trajectory tracking of end effector position. The controller performances are shown with graphics. It's shown that two-link planar robot manipulator can be simulated and controlled in Adams and Matlab with co-simulation.

This paper is organized as follows: in Section I introduction is given. In Section II, modelling and control of two-link manipulator with Adams and Matlab is given, followed by results and discussions are given in Section III. Finally, conclusion is drawn in Section IV.

II. MODELLING AND CONTROL

Modelling and controlling strategy of the system and the system model is given in Fig 1. To obtain the dynamic model of two-link planar robot manipulator, Adams software is used. System parameters which are shown in Table 1 are defined in Adams. Thus, more realistic model is acquired. Besides this, it is very important to Adams cooperate with Matlab/Simulink.

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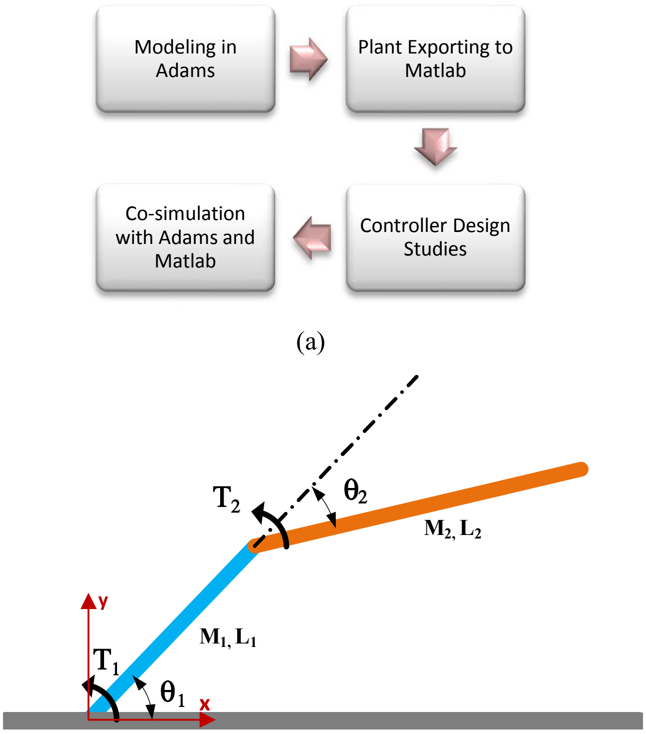

(a)

(b)

Fig. 1. (a) Strategy of the study and (b) the system model

The two-link planar robot manipulator is able to move in x-y plane. Firstly, the manipulator system is modeled in Adams. The Adams model has two inputs (torques of actuators) and four outputs (angle of 1st joint, angle of 2nd joint and x-y components of end effector position). The system parameters can be seen in Table 1. Then, created manipulator system is exported to the Matlab in order to perform controller design works in this software at the Simulink.

TABLE I. PROPERTIES OF TWO LINK ROBOT MANIPULATOR

M_1	Mass of the first link	1.2 kg
M_2	Mass of the second link	1.5 kg
L_1	Length of the first link	0.15 m
L_2	Length of the second link	0.2 m
I_{1zz}	Mass moment of inertia of the first link	1.8 kg.m^2
I_{2zz}	Mass moment of inertia of the second link	2.3 kg.m^2
T_1	Torque applied to the first link	N.m
T_2	Torque applied to the second link	N.m
θ_1	Angle of the 1st joint	Degree
θ_2	Angle of the 2nd joint	Degree

The controller design of the manipulator system is performed by using the sliding mode controller (SMC). SMC is a robust nonlinear control method which is insensible against external disturbing effects and parametric variations of the system. SMC is composed of two parts as reaching phase and sliding phase and its phase portrait can be seen in Fig 2. Firstly, sliding surface is designed for the system to be controlled. Then, the control signal which is switched in high frequency slides the state trajectories of the system to this surface in the phase portrait. The movement along this surface represents output action of the system. This movement in sliding surface represents the sliding mode. On the other hand, stage from the starting point to the sliding surface is called as reaching phase. If states of the system are on sliding surface, it provides durability against to parametric variations and disturbing effects.

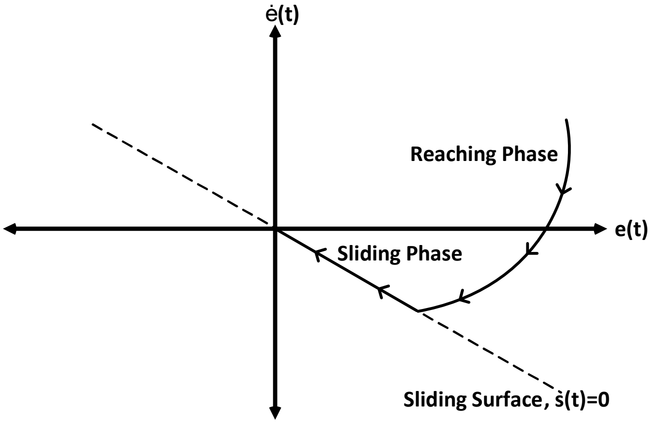

Fig. 2. Phase portrait of the SMC

During the implementation of the SMC, there is important relation between torques of actuators (*T_1* and *T_2*) and angles of joints (*$\theta_1(t)$* and *$\theta_2(t)$*). This relation has significant role to obtain the control signal (*$u(t)$*) which is applied to the input of the system. Main purpose of SMC is that controlled system output *$\theta(t)$* can track desired output *$\theta_d(t)$*. Additionally, *$u(t)$* which is minimized tracking error can be produced. Thus, the system reaches to sliding surface and error converges to zero in sliding surface.

For the angle of 1st joint of the manipulator, tracking error is defined as (1).

$$e(t) = \theta_{1d}(t) - \theta_1(t) \tag{1}$$

According to the tracking error, sliding surface can be determined as (2).

$$s = \dot{e}(t) + \lambda.e(t) \tag{2}$$

For reaching phase of SMC, the constant variation reaching law is used. This law can be represented by (3).

$$\dot{s} = -\mathrm{K}.\,\mathrm{sign}(s) \tag{3}$$

Where K is a positive value and sign() is the signum function defined as (4).

$$sign(s(t)) = \begin{cases} -1, & if\ s(t) < 0 \\ 0, & if\ s(t) = 0 \\ +1, & if\ s(t) > 0 \end{cases} \tag{4}$$

Description for sliding surface can be made as follows (5) and derivative of sliding surface is shown in (6).

$$s = \dot{e}(t) + \lambda.e(t) = \dot{\theta}_{1d}(t) - \dot{\theta}_1(t) + \lambda(\theta_{1d}(t) - \theta_1(t)) \tag{5}$$

$$\dot{s} = \ddot{\theta}_{1d}(t) - \ddot{\theta}_1(t) + \lambda(\dot{\theta}_{1d}(t) - \dot{\theta}_1(t)) \tag{6}$$

If $\theta_{1d}(t)$ is assumed a constant, the first and the second derivative of $\theta_{1d}(t)$ are zero. Thus, (6) is rewritten as in (7).

$$\dot{s} = -\ddot{\theta}_1(t) + \lambda\left(-\dot{\theta}_1(t)\right) = -K.sign(s) \tag{7}$$

Later, if these equations are synthesized, $u_1(t)$ control signal that is related with the angle of 1st joint of the manipulator is produced as (8).

$$u_1(t) = -\frac{m_1}{a_1}\left[\left(\frac{f_1}{m_1} - \lambda_1\right)\dot{\theta}_1(t) + \left(\frac{h_1}{m_1}\right)\theta_1(t) + K_1 sign(s)\right] \tag{8}$$

If the same procedure is applied for the angle of 2nd joint of the manipulator, $u_2(t)$ control signal is obtained as (9).

$$u_2(t) = -\frac{m_2}{a_2}\left[\left(\frac{f_2}{m_2} - \lambda_2\right)\dot{\theta}_2(t) + \left(\frac{h_2}{m_2}\right)\theta_2(t) + K_2 sign(s)\right] \tag{9}$$

The equations (8) and (9) are obtained by simulating the mass-spring-damper system. Here the coefficients (m_1, m_2, a_1, a_2, f_1, f_2, h_1, h_2) are related with the dynamics of the system. Others (K_1, K_2, λ_1, λ_2) are concerned with the controller. All these coefficients are determined by obtaining second order transfer functions by using Matlab/System Identification Toolbox.

The general block diagram including system modeling and controller design can be seen in Fig 3. The system is a multiple input – multiple output (MIMO) structure which consist of pre-defined two inputs and four outputs. The inputs are defined as controller (torques, N.m). Similarly, outputs are defined as angle of 1st joint (deg), angle of 2nd joint (deg) and x-y components of end effector position.

Also, the inverse kinematic equations of the planar manipulator are manually calculated to obtain angles of the joints which are used as reference of the control loop. Moreover, x-y components of the end effector position are investigated in order to check the trajectory tracking of the manipulator.

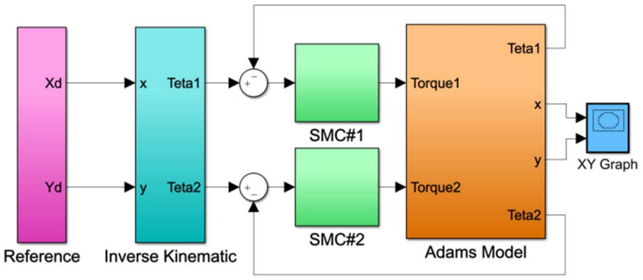

Fig. 3. Block diagram of the system

In the system, the trajectory which is composed of the starting point (0,350) and the endpoint (200,50) in x-y plane is expected to be followed by the manipulator. Firstly, the related angles of joints are manually calculated by using the inverse kinematics of the system. Then these angles are applied to the input of the system. The controller is always active during simulation period.

III. RESULTS AND DISCUSSION

In this part, the control approach is verified on the simulation. The controlled system responses and the simulation results are investigated to check the controller performance. For the desired angles of joints (Theta 1 and Theta 2), the inverse kinematics of the manipulator is manually acquired to use as the desired input of the system. The joint angles are shown in Fig 4 and Fig 5, respectively. It can be observed that the tracking performance of the manipulator is satisfactory for both angles of the joints.

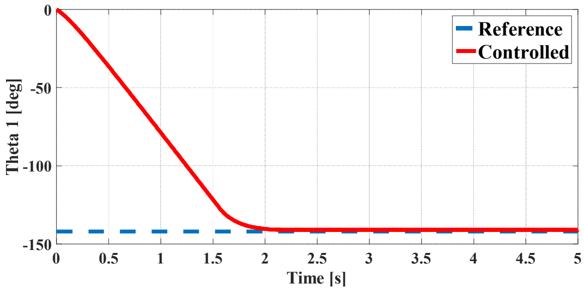

Fig. 4. Angular response of the system for Theta 1

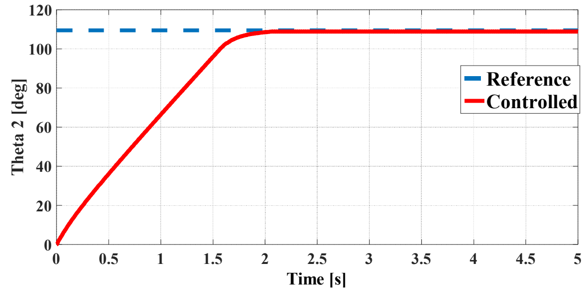

Fig. 5. Angular response of the system for Theta 2

Fig 6 and Fig 7 show the tracking response of the position of end effector in x-y plane, separately. The manipulator is successfully reached to the desired endpoint (200,50) in nearly 2 seconds.

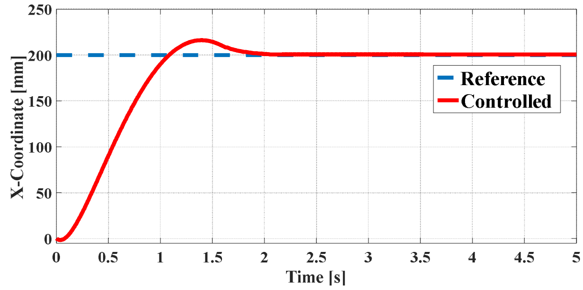

Fig. 6. Tracking response for x-coordinate

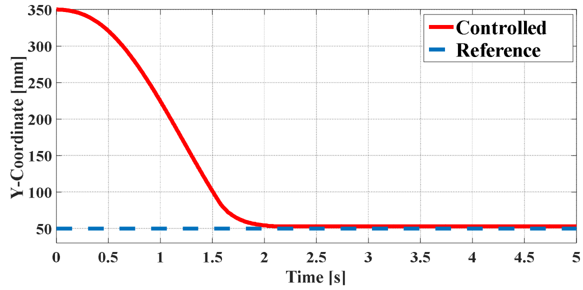

Fig. 7. Tracking response for y-coordinate

In Fig 8 and Fig 9, the errors and the derivative of errors for SMC for both joints are shown. In these figures, SMC forces successfully errors to the origin. When the external disturbing effects happen, the errors converge to zero.

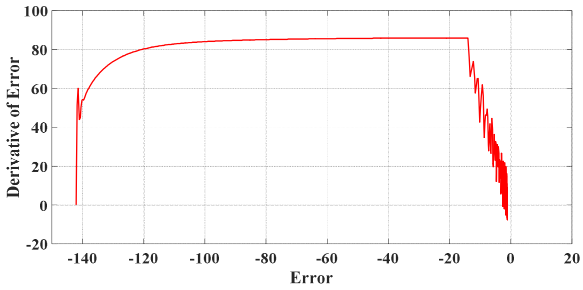

Fig. 8. Phase Portrait for Theta 1

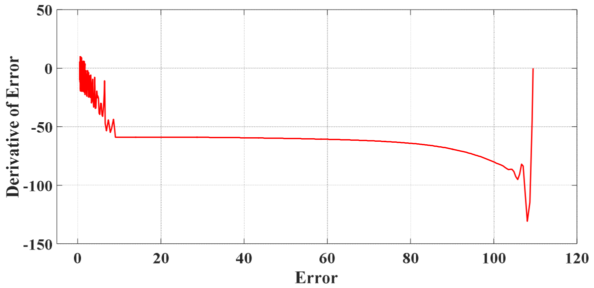

Fig. 9. Phase Portrait for Theta 2

IV. CONCLUSION

There is a lack of knowledge in simulating and controlling of the two-link planar robot manipulator systems with Adams and Matlab. In this study, it is shown that the two-link planar robot manipulator system can be simulated and controlled in Adams and Matlab. Also, for future works, this study can be base for simulation and control of the manipulator systems.

These systems have nonlinear characteristics. To develop realistic approaches to such kind of the system, effective software solution is very important. In this study, it is shown that Matlab and Adams are efficient in simulating and controlling the nonlinear systems like robot manipulators.

In this study, joints angles of the two-link planar robot manipulator are controlled. Controller design procedures and controller efficiency are shown with graphics. Thus, design parameters and required equipment for future works and experimental studies are determined.

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