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Simulation of a hybrid adaptive-learning control law for a rigid link electrically driven robot manipulator

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SUMMARY
In this work, a hybrid adaptive/learning controller is simulated in *Simulink* using a two-link robot manipulator for a sinusoidal desired position. The two-dimensional nature of control law makes direct simulation difficult. Simulation results demonstrate that the controller achieves semi global asymptotic position tracking.

KEYWORDS: Control law; Rigid link; Simulink; Position tracking; Electrically-driven robot.

I. INTRODUCTION

Messner[1] proposed a learning algorithm in which the uncertainties are modeled as an integral equation. Based on this, Canbolat[2] proposed a hybrid adaptive/learning control method, which achieves asymptotic position tracking, for robot manipulators. The learning and adaptive laws are introduced by several reseachers[1,3,4]. These learning control schemes could not be simulated directly due to the dynamic second time variable of the Hilbert-Schmidt kernel[2].

In this work, the hybrid adaptive/learning controller proposed by Canbolat[2] is simulated. A rigid-link electrically driven (RLED) two-link planar robot manipulator actuated by brushed DC (BDC) motors is used for simulation. Results show that the controller provides semi-global asymptotic trajectory following.

II. SIMULATION

Since the combined closed loop controller and robot manipulator system has two independent time variables[2], system simulation cannot be performed directly in *Simulink*, since it cannot handle two time arguments in a simulation. In order to keep the system in *Simulink* framework, we should have discretized the variable, γ, by taking 200 samples and defined new states at each discrete point since the equations are dynamically dependent on γ. The simulated system has 420 state variables. Due to huge number of nonlinear state equations, real-time simulation is impossible because of the computational burden. Validity of discretization in second variable is justified by the fact that all system variables are continuous and differentiable in both variables[2].

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A two-link planar elbow robot manipulator (Figure 1) is simulated. The manipulator dynamical matrices are given by

$$M(q) = \begin{bmatrix} (m_1+m_2)a_1^2 + m_2a_2^2 + 2m_2a_1a_2\cos q_2 & m_2a_2^2 + m_2a_1a_2\cos q_2 \\ m_2a_2^2 + m_2a_1a_2\cos q_2 & m_2a_2^2 \end{bmatrix} \tag{3.1}$$

$$V_m(q,\dot{q})\dot{q} = V(q,\dot{q}) = \begin{bmatrix} -m_2a_1a_2\left(2\dot{q}_1\dot{q}_2 + \dot{q}_2^2\right)\sin q_2 \\ m_2a_1a_2\dot{q}_1^2\sin q_2 \end{bmatrix} \tag{3.2}$$

$$G(q) = \begin{bmatrix} (m_1+m_2)ga_1\cos q_1 + m_2ga_2\cos(q_1+q_2) \\ m_2ga_2\cos(q_1+q_2) \end{bmatrix} \tag{3.3}$$

BDC motors actuate the links. Details of this model are found in Lewis[4] and Uguz[5].
Mechanical and electrical subsystem parameters are

$m_1 = m_2 = 50\,\text{kg}$, $a_1 = a_2 = 1\,\text{m}$,
$g = 9.8\,\text{m/s}^2$,
$L_1 = 0.163\,\text{H}$, $L_2 = 0.162\,\text{H}$,
$R_1 = 0.5\,\Omega$, $R_2 = 0.6\,\Omega$,
$K_{b1} = K_{b2} = 1270\,\text{Vs/rad}$,
$K_{\tau 1} = K_{\tau 2} = 1270\,\text{Nm/A}$.

The control gains were chosen as follows:

$$\sigma = 12, \quad K_L = 100I_2, \quad \Gamma_e = 3I_6, \quad k = 15$$
$$\|K_L\|_{i2}^2\kappa^2k_{n1} + k^4k_{n2} + k_{n3} + k_{n4} + k_{n5} + 1 = 256.$$

For the symbols, reader should refer to Canbolat[2] or Uguz[5]. The robot is supposed to track the following periodic desired trajectory

$$q_d = \begin{bmatrix} \cos(t) \\ \sin(t) \end{bmatrix}. \tag{3.4}$$

Position errors are shown in Figures 2 and 3. It can be seen that the position-tracking is achieved asymptotically and the errors for both links are less than 5% after 150 seconds.

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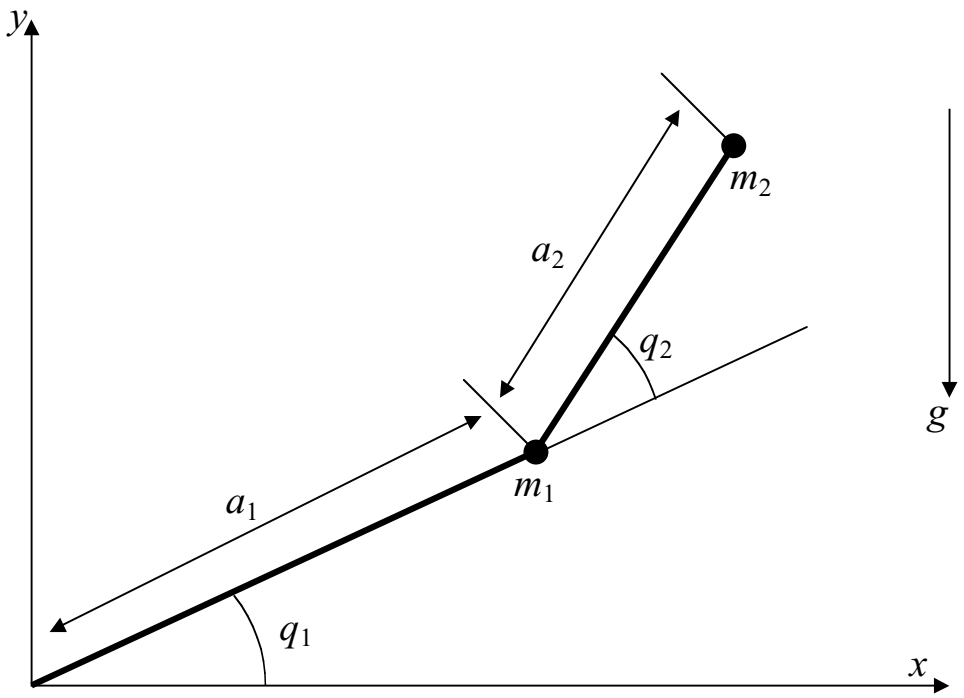


Fig. 1. Schematic Diagram of the Two-Link Elbow Arm Planar Robot Manipulator.

Therefore, the system should be trained for several periods before performing the actual task for precise operation.

Figures 4 and 5 depict velocity errors, while Figures 6 and 7 show current tracking errors. These four figures show that the controller provides asymptotical velocity and current tracking, additionally. Figures 8 and 9 show the input voltages, which are high due to high gain nature of the control and the high link masses.

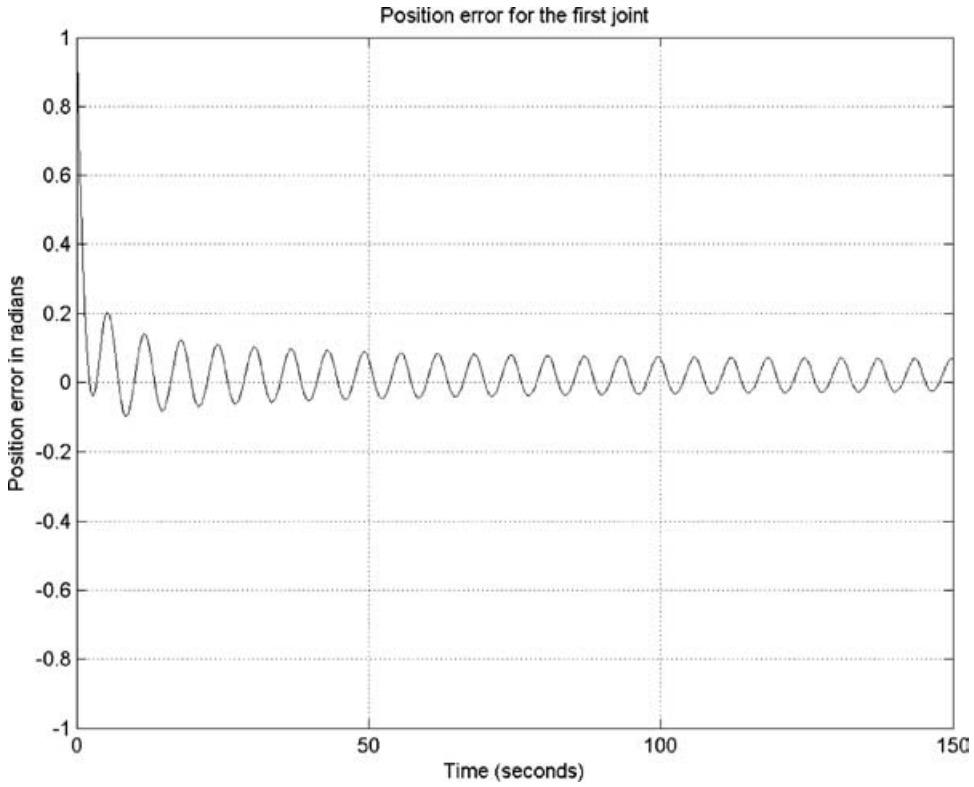


Fig. 2. Position error for the first link.

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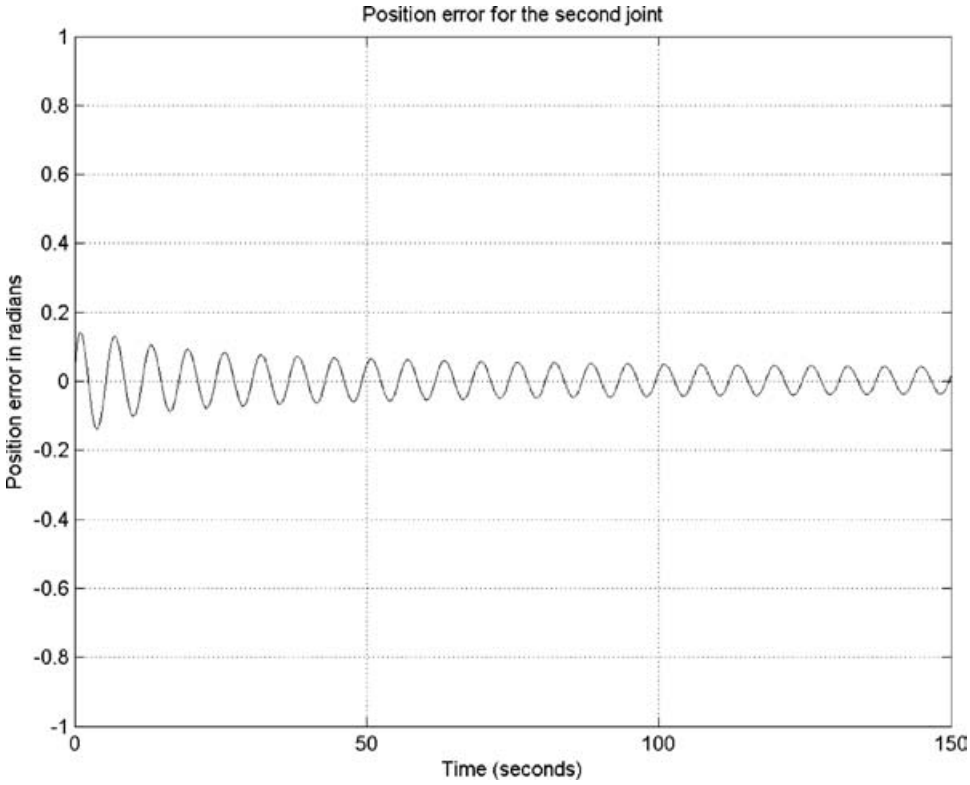


Fig. 3. Position error for the second link.

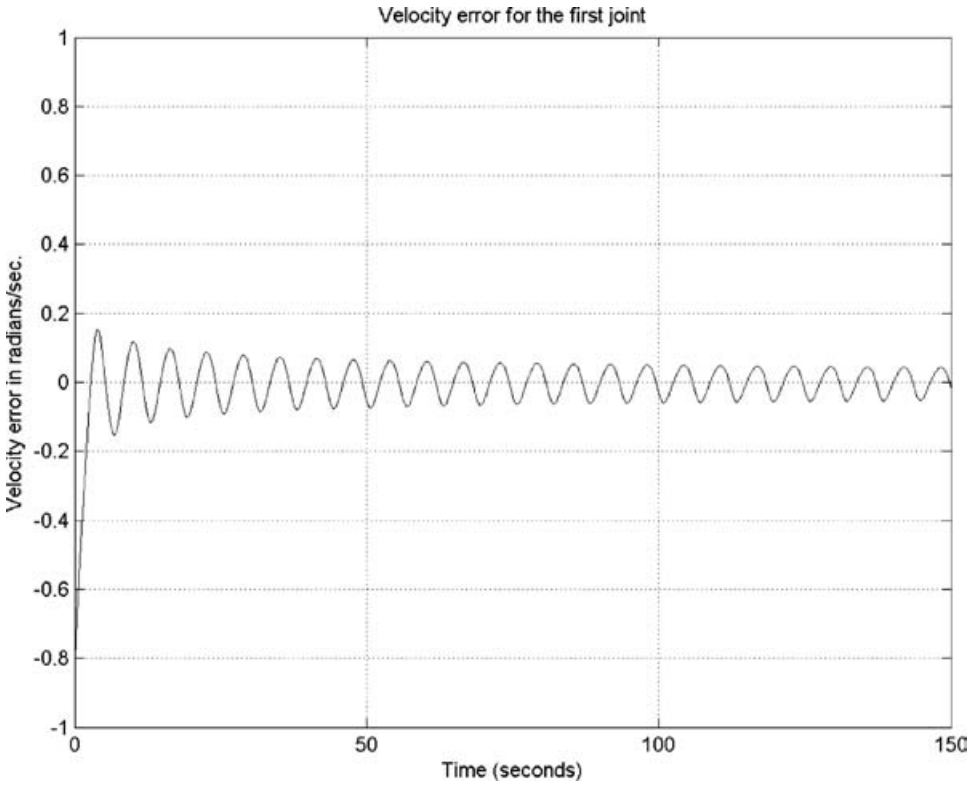


Fig. 4. Velocity error for the first link.

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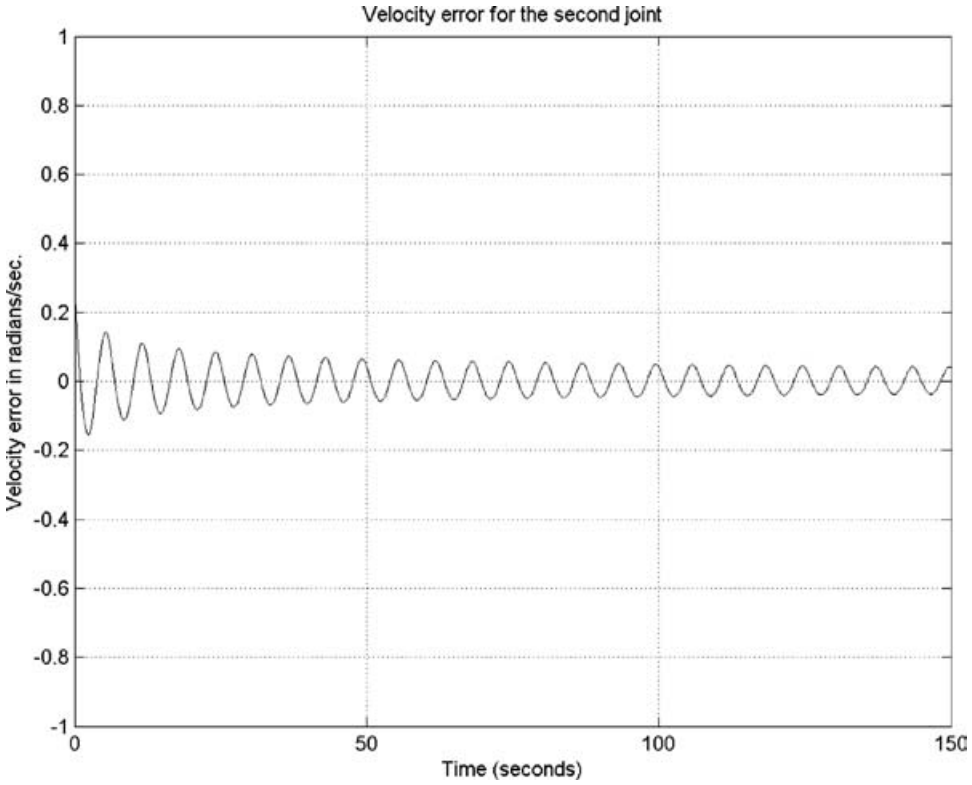


Fig. 5. Velocity error for the second link.

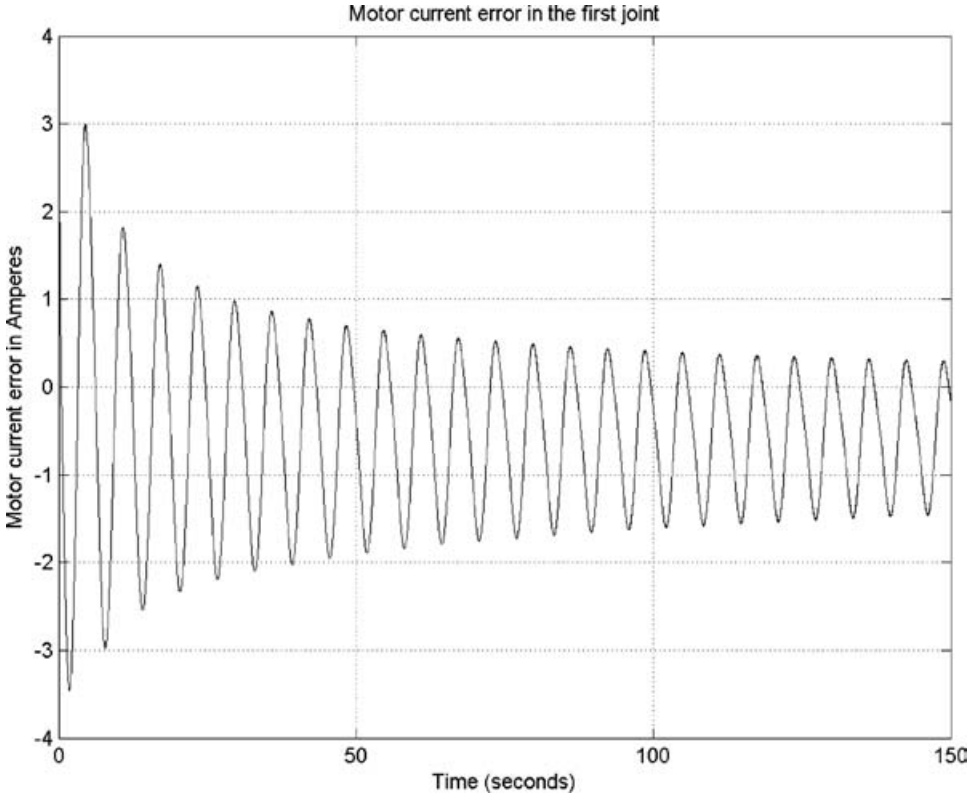


Fig. 6. Current error for the first link.

CONCLUSION AND DISCUSSION

In this work, the controller proposed by Canbolat[2] is simulated on a 2-link RLED robot manipulator in *Simulink*. Although the control objective is position tracking, the simulation results demonstrate that the controller asymptotically tracks the position and velocity.

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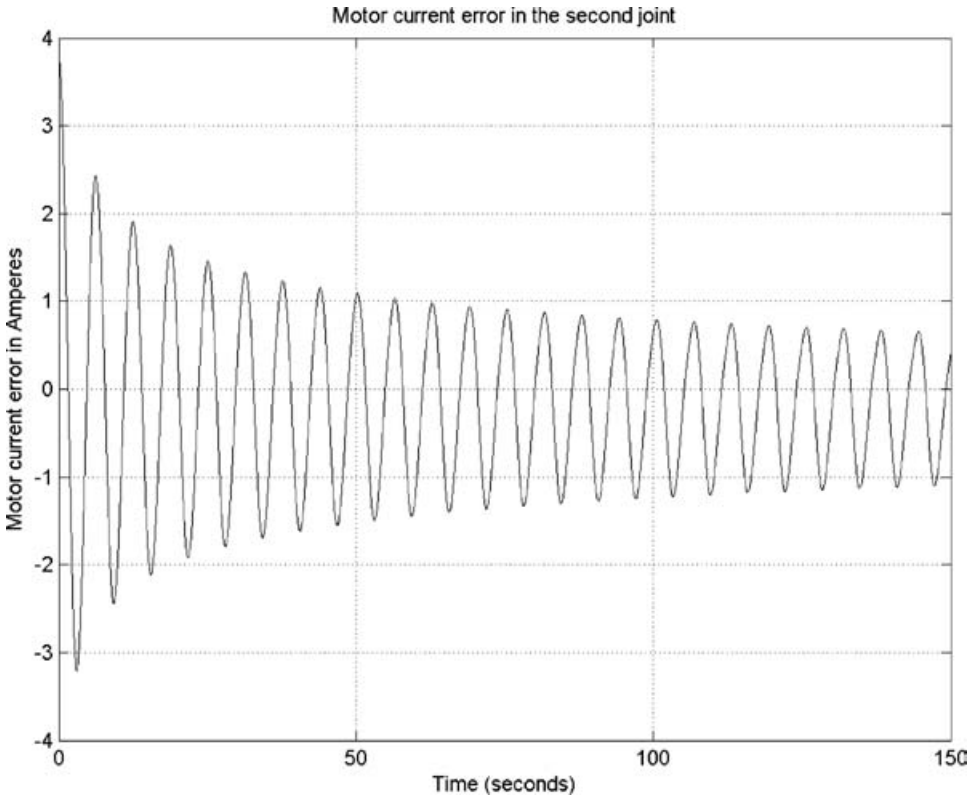


Fig. 7. Current error for the second link.

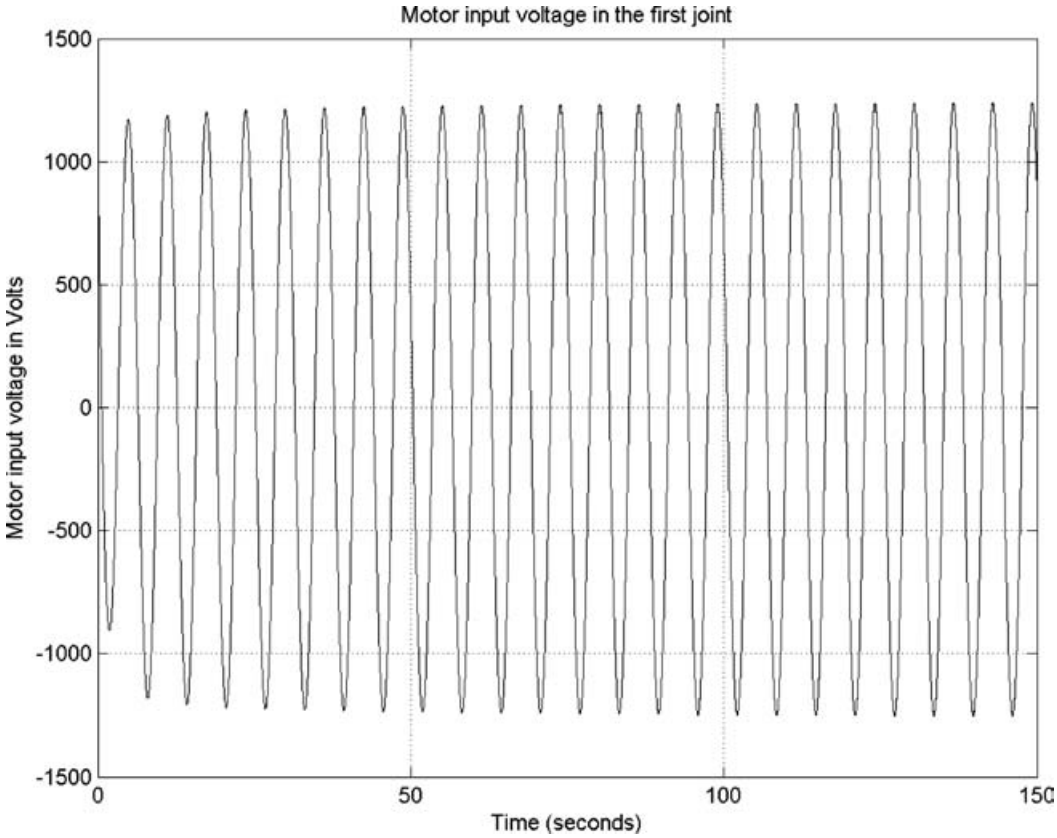


Fig. 8. Input voltage of the motor that actuates the first link.

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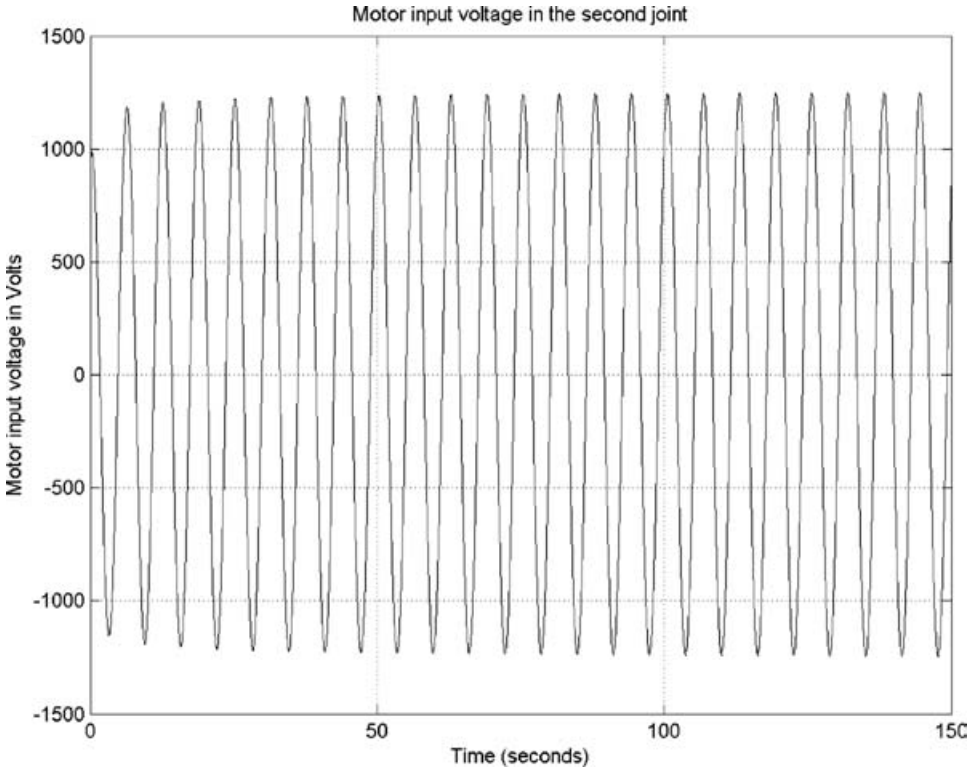


Fig. 9. Input voltage of the motor that actuates the second link.

Due to the distributed nature of the control law, simulation could be performed after a discretization.

Although simulation is successful for verifying that position-tracking objective is achieved, the algorithm cannot be employed for real-time control application because the computational burden is high. Simulation was performed 150 seconds for which the CPU spent 25 minutes on a PC with 667 MHz Celeron and 64MB of RAM. An efficient code should be developed for real-time control.

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