Design of one Nonlinear Adaptive Controller for a Robot Manipulator

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Abstract:

This paper represents an adaptive controller design for a robot manipulator in the presence of disturbances. At the outset of the design, the state space model robot has been presented. Contingent upon the variation of parameters like lump inertia, friction coefficients, rotor inertia, a technique has been utilized to devise an adaptive control for the nonlinear system. Further Lyapunov Stability theory has been applied to the dynamic system to ensure the stability of the overall system in spite of parameter uncertainty. The improvement in the performance of the proposed control law has been presented in the simulation environment.

Keywords- Adaptive control, Robot manipulator, State space model, Nonlinear system, Lyapunov stability theory.

I. INTRODUCTION

The motivation for developing model-based nonlinear robot controllers is to meet the demands created by industry for high-speed accurate tracking. The nonlinearity of robot dynamics, however, makes them even more complex to analyze than the linear dynamics systems. Several approaches have been considered. In 1987, Eppinger and Seering proposed the dynamics models for force control. Spong, Marino, Peresada, & Taylor (1987) discussed the problems of controlling electrically driven robots from the point of view of feedback linearization. Sadegh & Horowitz (1990) also studied the stability of Robotic System. In 1991, Abdallah, Dawson, and Jamishidi investigated the control of Robots. Dawson, Bridges, and Carroll (1991) proposed the tracking control of unbending connection electrically determined robots with framework vulnerability. Likewise, the control issue is additionally convoluted by the way that connects increasing speed estimations as are not permitted and, thus, the need of an exceptional strategy keeping away from control singularities is presented (Lozano, Brogliato, 1992). Hu, Dwan, & Qian (1996) also proposed the controllers for robot systems.

In the present work, the distinction is observed in terms of modification as the performance of transient response being improved for robot manipulator using the adaptive technique in spite of parametric uncertainties. The rest of the paper is sorted out as pursues. In section- II mathematical model is presented. Section –III presents the controller design. Section-IV presents the simulation results. Finally, Section-V concludes the paper.

II. MATHEMATICAL MODEL

In this section, we give the model for a robot manipulator driven by a brushed Dc-motor consisting of an electrical system and a mechanical subsystem. The dynamics of the mechanical subsystem along with the electrical subsystem is given below

$$M(d^2q(t)/dt^2)+B(dq(t)/dt)+N\sin q(t)=I(t)$$

……………… (1)

$$L(dI(t)/dt)+RI(t)+K_b(dq(t)/dt)=v(t)$$

.. …………… (2)

Where M denotes the lump inertia, B denotes the friction coefficients, N the rotor inductance, R the rotor resistance, L the rotor inductance, K_b the back emf constant, I(t) the motor armature current, q (t) the angular motor position and v (t) the control input voltage.

M and N are computed as

$$N=(\frac{m_1l_G}{2k_t})+(\frac{m_0l_G}{k_t})$$

$$N=(\frac{m_1l_G}{2k_t})+(\frac{m_0l_G}{k_t})$$

Where J denotes the rotor inertia, r_0 the radius of the load, m_0 the load mass, m_1 the link mass, l the link length, B_0 the viscous friction coefficient, G the gravity constant and k_t the torque constant of the motor.

Consider suitable state variable as x_1, x_2, x_3 and v (t) = u (t). Therefore, the state space representation can be described as follows:

$$dx(t)/dt=f(x(t))+g(x(t))u(t)$$

Where $x\in R^3$ and $u\in R^3$ and $f(x(t))$ and g(x (t)) are smooth function.

For the state space model, assuming states as

$$x_1(t)=q(t)$$
$$x_2(t)=\frac{dq(t)}{dt} \qquad \text{.. …………… (3)}$$
$$x_3(t)=I(t)$$

So,

$$\frac{dx_1(t)}{dt}=x_2(t)$$
$$\frac{dx_2(t)}{dt}=-\frac{N}{M}\sin x_1(t)-\frac{B}{M}x_2(t)+\frac{x_3(t)}{M}$$
$$\frac{dx_3(t)}{dt}=-\frac{k_b}{M}x_2(t)-\frac{R}{L}x_3(t)+\frac{u(t)}{L}$$

…………………. (4)

III. CONTROLLER DESIGN

In this section, we design an adaptive controller for the electromechanical dynamics in spite of parametric uncertainty. Define tracking error e(t) as

$$e(t)=q_d(t)-q(t)$$

.... (5)

Where $q_d(t)$ represents the desired trajectory

The filtered tracking error r(t) as

$$r(t)=(de(t)/dt)+\alpha e(t)$$

………………….. (6)

Where α is a positive constant controller gain.

Differentiate (6)

$$(dr(t)/dt)=(d^2e(t)/dt^2)+\alpha(de(t)/dt))$$
$$(dr(t)/dt)=(d^2q_d(t)/dt^2)+\alpha(de(t)/dt))-(d^2q(t)/dt^2)$$

…..…………….. (7)

Multiplying (7) by M

$$M(dr(t)/dt)=M(d^2q_d(t)/dt^2)+\alpha(de(t)/dt))-M(d^2q(t)/dt^2)$$

Substituting $\frac{M^2q(t)}{dt^2}$ from (1)

$$M(dr(t)/dt)=M(d^2q_d(t)/dt^2)+\alpha(de(t)/dt))+B(dq(t)/dt)+N\sin(q)-I(t)$$

……………..…… (8)

$$M(dr(t)/dt)=W_T\theta_T-I(t)$$

.... (9)

Where the regression matrix $W_T(q,(dq/dt),t)\in\Re^{1\times3}$ is given by

$$W_T = [(d^2 q_d / dt^2) + \alpha(de/dt) \quad (dq/dt) \quad \sin(q)]$$

.... (10)

and parameter vector θ_T as $[M \quad B \quad N]$

.... (11)

Consider an embedded current control I_c to the right-hand side.

$$M(dr(t)/dt) = W_T\theta_T - I_c + \eta$$

……………..…….. (12)

Where η represents a current perturbation to the mechanical subsystem dynamics of the form

$$\eta = I_c - I$$

……………….. (13)

Since the current perturbation is not equal to zero, in this manner we must design a voltage controller V_e which compensates for the effect of η .

Taking the time derivative in (13)

$$(d\eta/dt) = (dI_c/dt) - (dI/dt)$$

$$L(d\eta/dt) = L(dI_c/dt) - L(dI/dt)$$
$$L(d\eta/dt) = L(dI_c/dt) + RI + k_B(dq/dt) - V_e$$

…………….. (14)

We now design an adaptive controller for the open loop dynamics of (12) and (14).

Select I_c as

$$I_c = W_T\,\hat{\theta}_T + K_T r$$

….……….. (15)

Where $\hat{\theta}_T(t) \in R^3$ represents a dynamic estimate for the unknown parameter vector and k_T is a positive constant gain.

Using adaption law

$$(d\,\hat{\theta}_T/dt) = \Gamma_T W_T^T r$$

………….. (16)

Where $\Gamma_T \in R^{3\times 3}$ is a constant, positive definite, diagonal adaptive gain matrix.

$$\tilde{\theta}_T = \theta_T - \hat{\theta}_T$$

…………. (17)

$$(d\,\tilde{\theta}_T/dt) = -\Gamma_T W_T^T r$$

…………….. (18)

Substituting (15) into the open loop dynamics of (12) yields the closed loop filtered tracking error dynamics as shown

$$(dM_r/dt) = W_T(\theta_T - \hat{\theta}_T) - K_T r + \eta$$
$$(dM_r/dt) = W_T\,\tilde{\theta}_T - K_T r + \eta$$

Differentiate (15) with respect to time

$$(dI_c/dt) = (dW_T/dt)\,\hat{\theta}_T + K_T(d\,\hat{\theta}_T/dt) + K_T(dr/dt)$$

.... (20)

$$(dI_c/dt) =$$

$$[(d^3q_d/dt^3) + \alpha((d^2q_d/dt^2) - (d^2q/dt^2)) \quad (d^2q/dt^2) \quad (dq/dt)\cos(q)]\,\hat{\theta}_T$$
$$+W_T\Gamma_T W_T^T r + k_r((d^2q_d/dt^2) - (d^2q/dt^2) + \alpha(de/dt))$$

……………. (21)

From (1)

$$(d^2q/dt^2) = -\frac{B}{M}(dq/dt) - \frac{N}{M}\sin(q) + \frac{1}{M}I$$

. …………..… (22)

Substituting (d^2q/dt^2) for into (21)

$$(dI_c/dt) =$$

$$[(d^3q_d/dt^3)+\alpha((d^2q_d/dt^2)-\frac{B}{M}(dq/dt)-\frac{N}{M}\sin(q)+\frac{1}{M}I) \quad -\frac{N}{M}\sin(q)+\frac{1}{M}I \quad (dq/dt)\cos(q)]\hat{\theta}_T$$
$$+W_T\Gamma_T W_T^T r+k_r((d^2q/dt^2)-\frac{B}{M}(dq/dt)-\frac{N}{M}\sin(q)+\frac{1}{M}I+\alpha(de/dt))$$

……………………. (27)

Substituting (dI_c/dt) in (14)

$$L(d\eta/dt)=W_a\theta_a-V_e$$

……………..……….. (23)

Where the regression matrix $W_a(q,(dq/dt),I,t)\in R^{1\times 6}$

and unknown constant parameter $\theta_a\in R^6$.

$$\theta_a=\begin{bmatrix}\frac{L}{M} & \frac{L}{B}M & R & K_B & \frac{L}{N}M & L\end{bmatrix}^T$$

$$W_a=[W_{\psi 1} \quad W_{\psi 2} \quad W_{\psi 3} \quad W_{\psi 4} \quad W_{\psi 5} \quad W_{\psi 6}]$$

Where

$W_{\psi 1}=(\hat{B}I-K_T I-\alpha\hat{M}I)$,

$W_{\psi 2}=(K_T(dq/dt)-\hat{B}(dq/dt)+\alpha\hat{M}(dq/dt))$, $W_{\psi 3}=I$,

$W_{\psi 4}=(dq/dt)$,

$W_{\psi 5}=K_T\sin(q)-\hat{B}\sin(q)+\alpha\hat{M}\sin(q)$,

$$W_{\psi 6}=\hat{M}(d^3q_d/dt)+\alpha\hat{M}(d^2q_d/dt^2)+W_T\Gamma_r W_T^T r+K_T(d^2q_d/dt^2)$$
$$+K_r\alpha(de/dt)+\hat{N}(dq/dt)cos(q)$$

Define voltage level controller

$$V_e=W_a\hat{\theta}_a+k_e\eta+r$$

…………..……….. (24)

Where k_e is a positive constant gain.

The parameter estimates are updated online by the following adaption law

$$(d\hat{\theta}_a/dt)=\Gamma_e W_a^T\eta$$

…..……….……..….. (25)

Where $\Gamma_e\in R^{6\times 6}$

$$\tilde{\theta}_a=\theta_a-\hat{\theta}_a$$

…………..……….. (26)

$$(d\tilde{\theta}_a/dt)=-\Gamma_e W_a^T\eta$$

From Equation (23) and (24)

$$L(d\eta/dt)=W_a(\theta_a-\hat{\theta}_a)-k_e\eta-r$$

$$L(d\eta/dt)=W_a\tilde{\theta}_a-k_e\eta-r$$

……………..…….. (28)

Stability Analysis:

Consider the following Lyapunov function

$$V=\frac{1}{2}rMr+\frac{1}{2}\eta L\eta+\frac{1}{2}\tilde{\theta}_T^T\Gamma_r^{-1}\tilde{\theta}_T+\frac{1}{2}\tilde{\theta}_a^T\Gamma_e^{-1}\tilde{\theta}_a$$

……………..…….. (29)

Taking the derivative of the above equation

$$(dV/dt)=rM(dr/dt)+\eta L(d\eta/dt)+\tilde{\theta}_T^T(d\Gamma_r/dt)^{-1}(d\tilde{\theta}_T/dt)+\tilde{\theta}_a^T\Gamma_e^{-1}(d\tilde{\theta}_a/dt)$$

…….…………….. (30)

Substituting the error dynamics of (18), (19, (27) and (28) into (30) yields

$$(dV/dt)=-rk_T r-\eta k_e\eta$$

.... (31)

Since (dV/dt) is negative semi-definite. Thus, $\tilde{\theta}_T,\eta,\tilde{\theta}_e$ are all bounded.

IV. RESULTS

To investigate the planned control technique for accomplishing the ideal transient reaction, the proposed control schemes have been implemented in simulation environment using MATLAB software. The physical parameters belonging to the System taken as, J = 1.625 × 10^{-3} kg-m^{2}rad^{-1}, r_0 = 0.02 m, l = 0.3 m, R = 5.0 Ω, L = 25 × 10^{-3} H, m_0 = 0.45 kg, m_1 = 0.50 kg, G = 9.81 kg-ms^{-2}, B_0 = 16.25 × 10^{-3} N-m-s rad^{-1}, k_t = 0.90 N-m A^{-1} and k_b = 0.90 N-m A^{-1}. The system states (x1, x2 and x3) response and control input are shown in Figure1 and Figure 2.

Case 1: For control input u (t) = 0.1

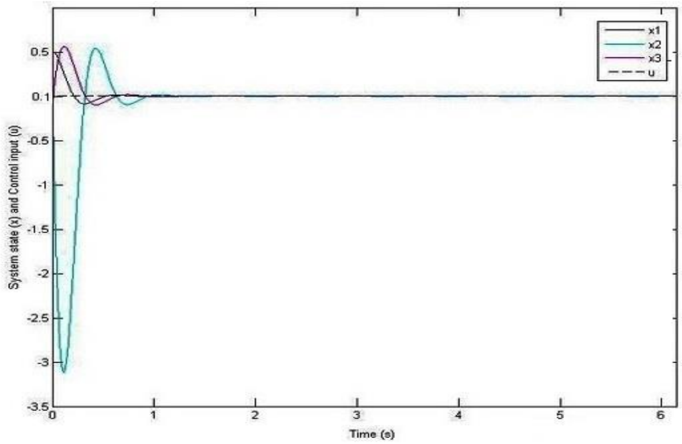

Figure1. System state and Control input

Case 2: For control input u (t) = 3*sin (t)

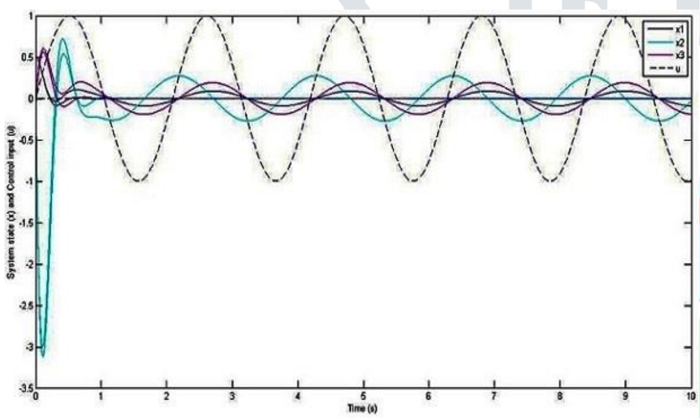

Figure2. System state and Control input

V. CONCLUSION

In this paper, designing the adaptive control for a robot manipulator system is considered. The performance of the robot with known and obscure dynamic and kinetic parameters in the presence of disturbance is examined as well. Theoretical analysis demonstrates that the controller is able to exhibit a performance in the vicinity of parametric vulnerability. The simulation results clearly exhibit the proficiency of the proposed control technique for an uncertain nonlinear system. Configuration using Lyapunov steadiness gives a stable versatile controller.

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