Developing a Robot Control Scheme Robust to Uncertain Model Parameters and Unmodeled Dynamics

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Abstract

In robot manipulators, inertia parameters of robot may be not known precisely and some dynamics such as friction torques that are usually difficult to be modelled and may be ignored. In this paper, we present a robust manipulator control approach that includes a feedback-feedforward compensation to compensate for the uncertain parameters and unmodeled dynamics and disturbances. The stability of the overall system is analyzed through Lyapunov direct method. For the proposed approach, global uniform asymptotic stability of the system is established. In addition, we present a continuous control law and guarantee the uniform ultimate boundedness of the tracking error. The simulation results are exhibited to support the theoretical issues.

1 Introduction

Accuracy of model plays an important role in stability and performance of model-based controllers. Inaccuracy of model may arise from inaccurate model parameters or from unmodeled dynamics. In the rapidly growing research on nonlinear control theory, much work has focused in the problems of uncertainties exist in the system model or systems with unknown disturbances and nonlinearities [1].

Spong [2] proposed a simple robust nonlinear control for robot manipulators. One of the advantages of his approach respect to previous applications of the Leitmann approach to robot manipulators [3]-[4] lies in the fact that the uncertainty bounds needed to derive the control law and prove uniform ultimate boundedness of the tracking depends only on the inertia parameters of the robot. [3]-[4] have required uncertainty bounds that depend not only on the inertia parameters but also on the reference trajectory and on the manipulator state vector, consequently, precise bounds on the uncertainty have been difficult to compute. Another advantage of [2] is removing of the assumption of *closeness in norm* of the computed inertia matrix to the actual inertia matrix, required for [4]-[5]. However, disturbances and unmodeled dynamics are not considered in algorithm of [2].

In this paper, we develop the Spong's approach [2] in such a manner that the control system is made robust not only to uncertain inertia parameters but also to unmodeled dynamics and disturbances. The organization of the rest of paper is as follows. In Section 2, motion equation of a rigid robotic arm is described. In Section 3, the design of the proposed robust robot control system is explained. Simulation results and conclusion remarks are presented in Sections 4 and 5, respectively.

2 Motion Equation of Robotic Arm

Consider an n links robotic arm for which: $q, \dot{q}, \ddot{q} \in R^n$ are the vectors of joint displacement, velocity and acceleration, respectively; $\tau \in R^n$ is the vector of joint torques supplied by the actuators; $M(q) \in R^{n \times n}$ is the arm mass (inertia) matrix which is symmetric and positive definite (pd); $V_m(q, \dot{q}) \in R^{n \times n}$ is a matrix derive based on centrifugal, Coriolis forces; $G(q) \in R^n$ is the vector of gravitational forces; $\tau_d(t) \in R^n$ represents the effects of unmodeled dynamics and disturbances. The motion equation of such robotic arm in joint space is as follows

$$\tau = M(q)\ddot{q} + V_m(q, \dot{q})\dot{q} + G(q) + \tau_d \tag{1}$$

(1) can be expressed as

$$\tau = Y_1(q, \dot{q}, \ddot{q})\theta + \tau_d \tag{2}$$

where $Y_1 \in R^{n \times m}$ is called the regressor matrix and $\theta \in R^m$ is the vector of inertia parameters. This property is called linear parameterization property. Another property of (1) is skew-symmetric property and states that by a suitable definition of matrix V_m, $\dot{M} - 2V_m$ is a skew-symmetric matrix where $\dot{M}$ is the time derivative of M [6]-[8].

It is assumed that the above system satisfies the following assumptions.

Assumption 1: The uncertain function $\tau_d(t)$ is bounded in norm by a known constant upper bound. In other word,

$$\|\tau_d\| < d \tag{3}$$

where d is a real positive constant.

Assumption 2: The parameter vector θ is *uncertain* by which we mean that there exists $\theta_0 \in R^m$ and $\rho \in R^+$, both known, such that

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