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Direct Adaptive Robot Control in the Presence of Force Disturbances and Parameter Uncertainties

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Abstract

In this paper enhancing the performance of robot control system is intended in the situations that external force disturbances are exerted on the robot, inertia parameters of robot are unknown, and no force sensor is available. Stability analysis of the proposed approach is supported by a theorem to guarantee the global uniform asymptotic stability of the proposed non-autonomous control system. Satisfactory performance of the closed loop system is shown through simulation.

1 Introduction

Utilizing force feedback to compensate for the force disturbances enhances the performance of the robot control system. Force sensors can provide the force feedback. However, force sensors have some problems such as high price, impossibility to mounting on robot in some environmental uncertainties (e.g. high temperature and large noise) [1] and making the structure of manipulator complicated [2]. Thus, using force estimation instead of force measurement seems to be an appropriate strategy. On the other hand, accuracy of robot control approaches in high-speed operations and also accuracy of force estimation are greatly affected by the parameter uncertainties. This sensitivity is especially severe for direct drive robots [3]. Employing observers is popular in motion control [4-9] to compensate for the disturbances.

Accurate robot modeling is required in some of approaches such as [4] presented by Ohishi et al. and [5] presented by Hacksel and Salcudean. Therefore, the modeling uncertainties may result in the force estimation errors. In the Eom et al.'s method [1], the force information is derived from the total disturbance created by modeling uncertainties and external force, based on using disturbance observer and its output estimator. However, some restrictive assumptions and simplifications are considered in their algorithm such as measuring the joint acceleration and simplifying the inertia matrix to a constant diagonal form matrix. Also, they utilized linear disturbance observer and did not present any proof for stability of the whole system.

In this paper, a new strategy is developed to compensate for the force disturbance, based on an adaptive control algorithm. Adaptive controllers of robot manipulators can be divided into two main categories, passivity-based and inverse dynamics (or computed torque). Advantages of passivity-based adaptive controllers in comparison to adaptive computed torque controllers are preserving the passive structure of robot, and requiring no acceleration measurement and no invertibility of the estimated inertia matrix [10]. The proposed approach in the present paper adds to the passivity-based direct adaptive algorithm of [3, 12] the ability of cancellation of external force disturbances exerted on the system without using any force sensor or requiring the assumptions and simplifications of [1].

In this paper, we consider the case that the robot dynamics have unknown parameters and at the same time robot is subjected to the external force (both force and torque) disturbances. In this approach, uncertain parameter vector and external force vector are simultaneously estimated and then used in the control law. Time varying Lyapunov stability method and invariant set theorems are utilized for stability analysis and proving the global convergence of tracking and estimation errors.

Organization of the subsequent parts of this paper will be as the following. The proposed approach for adaptive control by simultaneously estimation of force and parameters and its stability analysis are presented in Section II. Demonstrating the simulation results of this approach is allocated to Section III. The paper concludes in Section IV.

2. Design and Analysis of the Control Algorithm

The motion equations of a mechanical system in local joint coordinates, q, in the presence of forces arising from *(i)* the earth's gravitational potential, g, *(ii)* independently controlled torque joint, τ, and *(iii)* an external force exerted on the system, F_{ext}, take the form:

$$M(q)\ddot{q} + V_m(q,\dot{q})\dot{q} + G(q) = \tau + J^T(q)F_{ext} \qquad (1)$$

where $M(q)$ and $V_m(q,\dot{q})$ are respectively the inertial and Coriolis matrices and $J(q)$ is the Jacobian. $J(q)$ includes the Jacobians of end-effector and all links that external forces exerted on them. Based on linear parameterization property of motion equations, one can write

$$M(q)\ddot{q} + V_m(q,\dot{q})\dot{q} + G(q) = Y_1(q,\dot{q},\ddot{q})\theta \qquad (2)$$

where θ is the parameter vector, and Y_1 is the regression matrix with certain functions as its components. Usually, θ consists of unknown parameters.