An Adaptive Manipulator Controller Based on Force and Parameter Estimation

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SUMMARY Consideration of manipulator dynamics and external disturbances in robot control system design can enhance the stability and performance properties of the whole system. In this paper, we present an approach to solve the control problem when the inertia parameters of robot are unknown, and at the same time robot is subjected to external force disturbances. This approach is based on simultaneous estimation of force signal and inertia parameters and utilizing them in the control law. The update laws and the control law are derived based on a single time-varying Lyapunov function, so that the global convergence of the tracking error is ensured. A theorem with a detailed proof is presented to guarantee the global uniform asymptotic stability of the whole system. Some simulations are made for a number of external forces to illustrate the effectiveness of the proposed approach.

key words: *adaptive control, force estimation, parameter estimation, disturbance rejection, non-autonomous systems, uniform stability, invariant set*

1. Introduction

Environmental forces are exerted on the system in many robotic tasks. In some robotic applications such as deburring, grinding and precise assembly, it is required that end-effector contacts with environment and maintains this contact [1]. Also, in robotic assembly for odd form electronic components, the success of work severely depends on the ability to monitor and control the insertion force. Component misinsertion can be detected based on the reaction force [2]. For correct use of robot in such cases, force must be considered in control system. This force may be act as a disturbance in some applications. For example, the unexpected external force to a mobile manipulator makes its motion unstable since there are no fixed points in stationary coordinates [3].

For force compensation, one way is to use force sensor to measure the force and then use the measured value in the controller. However, the typical price of force sensor is high. In addition, when manipulator is affected by environment uncertainties such as high temperature and large noise, force sensor cannot be mounted on the robot [4]. On the other hand, even for the cases that force sensor can be used easily, mounting the sensor on robot makes the structure of manipulator complicated [5]. On the other hand, accuracy of robot control approaches in high-speed operations is greatly affected by the parameter uncertainty [6]. To deal with uncertainties in robot control systems, various methods have been propose such as [7]-[10].

In our previous work [11], we proposed an approach to reject external force disturbance in robotic arms without use of any force sensor. Although [11] has a high performance, it requires accurate robot modeling; therefore, the modeling uncertainties may result in the force estimation error.

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 forces (both forces and torques) disturbances. We propose an approach in which uncertain parameters vector and external force vector are simultaneously estimated, and then both are utilized in the control law. Applying the estimated forces to the control law is intended to reject the force disturbances. Lyapunov analysis of non-autonomous systems and invariant set theorems are used for stability analysis and proving the global convergence of tracking and estimation errors. Due to the global convergence, all of the estimated variables may initially set to any arbitrary values such as zero or nominal values. Also, this approach contains the following advantages. Measurement or computation of the joint accelerations and considering the inertia matrix as a constant diagonal matrix are not required (advantage over some algorithms such as the algorithm of [1]). The system is stable and there is no need to assume that joint reference position, velocity and acceleration are bounded (advantage over some adaptive algorithms such as the algorithm of [12]). The proposed approach is adaptive, thus, the accuracy of system improves with time (because the adaptation mechanism keeps extracting parameter information from tracking errors).

In addition to overcoming the drawbacks of using force sensors, an advantage of the proposed approach is the capability of computation and compensation for the forces and moments exerted on links in addition to those exerted on end-effector. For instance, in an underwater vehicle-manipulator system (UVMS) underwater flows exert forces on links.

Organization of the paper is as follows. The proposed adaptive robot control system and its stability analysis are presented in Section II. Demonstrating the simulation results of this approach on a planar revolute manipulator is presented in Section III. The paper concludes in Section IV.

2. Adaptive Manipulator Controller Analysis and Design

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