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A Force Estimator Based Algorithm for Robot Control

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***Abstract*- Modifying the control algorithms to eliminate some sensors is a popular methodology to overcome the drawbacks associated with the using of these sensors. Complicating the structure of robot, impossibility to mounting on manipulator in high temperature and large noise, and high price are problems associated with the using of force/torque sensors. With this motivation, a scheme is presented in this paper to eliminate force/torque sensors. Desirable properties of the proposed scheme in the aspects of global uniform asymptotic stability, satisfactory estimation and effective tracking control are shown through strong detailed proofs and various simulation results.**

Index Terms – Force estimation, force sensor, adaptive control, manipulator.

I. INTRODUCTION

Main problems of utilizing force/torque sensors are: their prices are high, mounting them on robot in high temperature and large noise environments is not possible [1], using them complicates the structure of robot [2] and taking account the rigidity of them in motion control of manipulators is necessary which is very difficult [3].

In order to overcome these problems, a number of approaches have been developed. Employing observers is popular in motion control [1-8]. Although the disturbance observers perform desirable model regulation and disturbance rejection, they introduce problems in stability and stability robustness of the system due to the use of feedback [4]. Many important properties of existing disturbance-observers have not been established, e.g., unbiased estimation or even global stability [5]. Also, even though in some of these approaches, properties such as global stability are proved, they are developed for special cases; for example, only for two-link manipulators [5] or only for systems with Coulomb friction [6].

In this paper, a new scheme is introduced to estimate and reject the external force disturbances (rather than desired force control). Stability analysis of the proposed control system is accurately carried out in the paper.

In the first glance, the selected Lyapunov function may seem to be similar to that selected by Spong-Ortega-Kelly and Slotine-Li [9, 10]; however, some main differences exist. Firstly, in the proposed scheme, the estimated values are components of the external force vector (consisting of external forces and torques exerted on the system), and the inertia parameters (link masses, moments of inertia, etc.) of the robot are known. While in [9, 10], the estimated values are components of the inertia parameter vector and it is assumed that no external force is applied to robot. Hence, the aim of control in [9, 10] is trajectory control with no force disturbance by using estimation of the inertia parameters, while in the proposed scheme, both force and position are considered, and enhancing the trajectory tracking results from force estimation and compensation. Secondly, in [9, 10] the skew-symmetry property is required in the design of the control system, whereas this property is not necessary in the present work and it has no restriction on use.

This paper consists of four sections. Section II discusses the proposed adaptive control algorithm, which is based on external force disturbance estimation. Section III shows some simulation results to verify the performance of the proposed scheme. Finally, Section IV gives some concluding remarks.

II. PROBLEM FORMULATION AND CONTROLLER DESIGN

In this section, we assume that the motion equations of robot are given. Then we derive the corresponding force estimation and control laws.

Dynamic equations of an n link robot are well known as

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

where $q \in R^n$ is the vector of joint variables, $M(q)$ is the inertia matrix, $h(q,\dot{q})$ is the vector that consists of Coriolis/centripetal and gravity torques, τ is the joint torque vector, F_{ext} is the external force (and moment) vector exerted on the system, and $J(q)$ is the Jacobian matrix. $J(q)$ includes the Jacobians of end-effector and all links that external forces exerted on them.

Assume that $\hat{f}$ is the estimation of F_{ext} and define the force estimation error as $\tilde{f} = F_{ext} - \hat{f}$. Also, assume $q_d(t)$ to be a given twice-differentiable desired trajectory in joint space, and $e(t) = q_d(t) - q(t)$ defines the trajectory tracking error. In order to obtain control and estimation laws, making the control system stable with appropriate performance, the following theorem is presented and proved.

Theorem: Consider the robot control system of Fig. 1 with dynamic equation (1), update law $\dot{\tilde{f}} = K_f^{-T} Jr$ and control law $\tau = M(\ddot{q}_d + \Lambda\dot{e}) + h + (\frac{1}{2}\dot{M} + K)r - J^T\hat{f}$ where Λ, K and K_f are constant positive definite matrices and $r = \dot{e} + \Lambda e$. Then,

a) the tracking error goes asymptotically to zero, the force estimation error is bounded, and the closed-loop system is