# Adaptive Position/Force Control of Robot Manipulators with Force Estimation


Mohamadreza Homayounzade
Dept. Mechanical Engineering
Isfahan University of Technology (IUT)
Isfahan, Iran
m.homayounzade@me.iut.ac.ir

Mehdi Keshmiri
Dept. Mechanical Engineering
Isfahan University of Technology (IUT)
Isfahan, Iran
mehdik@cc.iut.ac.ir



***Abstract*—In this paper, we design an adaptive position/force controller for robot manipulators during constrained motion. The proposed controller can compensate for parametric uncertainties while only requiring the measurements of the position and velocity of robot arms, but not the measurements of forces at contact points. A disturbance observer is designed to estimate the constraint forces. The control method results in semiglobal asymptotic tracking performance for the joint position and bounded tracking performance for the interaction force, also the controller provides proper estimate of constraint forces. It is shown mathematically that the error of tracking desired constraint force can be decreased sufficiently by increasing the control gains. The effectiveness of the proposed method is investigated through the numerical simulation for a two-degrees-of-freedom robot manipulator acting on a horizontal worktable.**



***Keywords*—adaptive systems; position/force control; force estimation; stability analysis**


## I. Introduction

In many applications of robot such as automated deburring, grinding, spot welding, scribing and precision assembly, robots are being used to perform tasks which require a contact between the robot and the workpiece. This interaction with the environment will constrain the robot motion. Consequently robotics force control is important because it not only prevents excessive contact force which could damage the workpiece, but also regulates the desired force.

So far, several force control algorithms have been proposed in the academia over the past four decades. In spite of their diversities, they can be classified into three main groups: hybrid P/F (position/force) control, hybrid impedance control, and reduced state P/F control methods.

The hybrid control approach, aims at controlling position along the unconstrained task directions and force along the constrained task directions [1],[2]. As introduced in [3],[4], the objective of an impedance controller is to maintain a desired dynamic relationship between the end-effector and the environment. These two approaches are more efficient if a precise model of the environment is available.

Reduced state P/F control method deals with the transformation of the robot dynamics into a reduced order one in which the constraint force is omitted. In [5], McClamorch and Wang developed a nonlinear transformation that amends the system dynamics into a reduced one in which the force and motion controller can be designed separately. Their controller ensures asymptotic position tracking and bounded force tracking error.

In order to compensate the system uncertainties, in [6], Carelli and Kelly presented an adaptive full state feedback controller which ensures asymptotic position tracking and bounded force tracking error. Moreover, an adaptive feedback P/F tracking controller was presented in [7]-[9].

In order to control the contact force, the force sensors data should be fed back to the controller. Conventionally, a force sensor attached to the wrist of manipulator is used to measure the contact force. However, force sensors are not popular in industrial application due to their high price. Additionally, the information of a force sensor has much noise and when the robot manipulator encounters environmental uncertainties such as high temperature and large noise, the force sensor cannot be mounted on it.

To overcome these difficulties, various force estimation methods have been proposed [10]-[13]. One approach is utilizing disturbance observer as a surrogate for force sensor. Disturbance observers consider deviations from the nominal dynamical model of the robot as an equivalent disturbance applied to the nominal model. Consequently, the output of the disturbance observer represents the external torque plus the system uncertainties. In [12], the external torque is obtained by subtracting the established modeling uncertainties from the output of disturbance observer. However, their method requires the accurate nominal model and the modeling uncertainties may engender the force estimation errors. In [10],[11], the force is estimated by considering how position estimation errors behave as a damped spring-mass system. Disturbance observers have been also used in robotic systems for hybrid P/F control where the disturbance observer works as a torque sensor [12].

It seems that the problem of force sensor free P/F controller design utilizing reduced position/force control method still remains an open forum. Considering this challenge and motivated by the concept of utilizing disturbance observer for P/F control of robotic systems, in this paper an adaptive force estimator is developed to estimate the constraint force. Afterward, this estimated force has been used to design the P/F controller without force measurements. Additionally, an adaptive parameter estimator is designed to compensate and learn the effects of the system parametric uncertainties.

The rest of the paper is organized as follows. In section II a representation of an arbitrary time varying vector in terms of Taylor series is presented and in section III, we present the constrained robot model along with some useful properties associated with the model. In section IV, the system error dynamics and a force sensor free P/F controller is introduced and the stability of the controller is analyzed by the Lyapunov theorem. In section V simulation results of the proposed controller for a two-link robot arms are given to serve as validation of the theoretical development. Finally, some concluding remarks are given in section VI.


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