Adaptive robust hybrid position/force control for a uncertain robot manipulator

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Abstract

When real robot manipulators are mathematically modeled, uncertainties are not avoidable. The uncertainties are often nonlinear and time varying. The uncertain factors come from imperfect knowledge of system parameters, payload change, friction, external disturbance and etc. We proposed a class of robust hybrid position/force control of manipulators and provided the stability analysis in the previous work. In the work, we propose a class of adaptive robust hybrid position/force control of manipulators with bound estimation and the stability based on Lyapunov function is presented. Especially, this controller does not need the information of uncertainty bound. The simulation results are provided to show the effectiveness of the algorithm.

1. Introduction

For a robot manipulator during contact tasks, such as grinding, deburring and mechanical assembly, the end-effector of robot manipulator is required to keep contact with the environment and to apply certain amount of work to the workpiece. To ensure positioning accuracy and to avoid damaging either the end-effector or the workpiece, it is necessary to simultaneously control both the motion of the end-effector and the force that the manipulator end-effector exerts on the workpiece.

To accomplish these tasks efficiently and accurately, a variety of manipulator controllers have been developed. Among them, most commercial robots use simple PD or PID control scheme. Surprisingly, these control schemes may asymptotically stabilize the robot in the sense of Lyapunov and satisfactory performance may also be accomplished for low-speed motion. However, for high-speed motion the coupling effects due to centrifugal, coriolis and gravity terms become active and the PD or PID controllers are no longer acceptable. Also, it's difficult to do the correct modeling between robot manipulator and environment. Namely, the dynamics of robot manipulator include uncertainty such as incorrect parameter, friction, varying payload and disturbances and etc.

The robust approach is to solve this problem as uncertainties are introduced in a model and the controller can achieve the desired properties in spite of the imperfect modeling. The deterministic robust control design of manipulators can be found in, e.g., Chen[1], Chen and Pandey[2], Reithmeier and Leitman[3], Shoureshi et al.[4], Han[5,6], and their bibliographies.

In the previous work, we proposed a class of robust hybrid position/force control of robot manipulator and analyzed the stability. In more general case, to achieve the work which the information of uncertainties bound is lack, we propose a robust hybrid position/force control with adaptive algorithm and analyze the stability in sense of Lyapunov. The adaptive algorithm estimates the bound of uncertainties and the robust control uses the bound estimation.

The simulation results of 4-axis SCARA type robot are provided to show the effectiveness of the proposed algorithm.

2. Robot Dynamic

The joint coordinate model of the m-link robot manipulator is derived from the Newton-Euler equations, which can be written as :

$$M(q)\ddot{q}+C(q,\dot{q})\dot{q}+g(q)+f(q,\dot{q},t)=\tau-J(q)^T R \tag{1}$$

q : $m\times 1$	joint position vector
$M(q)$: $m\times m$	inertia matrix
$C(q,\dot{q})\dot{q}$: $m\times 1$	centrifugal and coriolis vector
$g(q)$: $m\times 1$	gravity vector
$f(q,\dot{q},t)$: $m\times 1$	friction force vector
τ : $m\times 1$	torque vector
R	reaction force

To do contact task, we need the dynamic equation of cartesian coordinate. The Jacobian $J(q)$ between the cartesian and the joint coordinate is given by :

$$\dot{x} = J\dot{q}\ ,\quad \ddot{q} = J^{-1}(\ddot{x} - \dot{J}\dot{q}),\quad x\in R^n \tag{2}$$

By substituting (2) into (1), we have

$$M_x(q)\ddot{x}+C_x(q,\dot{q})\dot{x}+g_x(q)+f_x(q,\dot{q},t)=\tau_x - R \tag{3}$$

$$M_x(q) = J^{-T}M(q)J^{-1}$$
$$C_x(q,\dot{q}) = J^{-T}(C(q,\dot{q}) - M(q)J^{-1}\dot{J})J^{-1}$$
$$g_x(q) = J^{-T}g(q)$$
$$f_x(q,\dot{q},t) = J^{-T}f(q,\dot{q},t)$$
$$\tau_x = J^{-T}\tau$$

Remark 1. The inertia matrix $M_x(q)$ is symmetric and positive definite. The nonlinear term $C_x(q,\dot{q})$ in (3) can be suitably chosen such that $\dot{M}_x(q)-2C_x(q,\dot{q})$ is skew symmetric. The $f_x(q,\dot{q},t)$ include the torque that