ROBOT CONTROL WITH INVERSE DYNAMICS AND NON-LINEAR GAINS

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Abstract— A motion control strategy for robot manipulators, with inverse dynamics and non-linear proportional-derivative gains is presented. On account of a possible interaction of the robot with the environment, impedance is incorporated to modify the robot's motion references according to the interaction force. The gains, that are non-linear state functions, allow to improve robot performance and to prevent actuator saturation. It is proved that an asymptotically stable closed-loop system is obtained with the proposed controller. Simulation results on a 3-dof robot show a good performance of the controller with variable gains, as opposed to that of a constant gain PD controller.

Key words— robotics, non-linear systems, motion control, impedance control.

I. INTRODUCTION

One of the basic problems in robot control is the so-called motion control, when a robot manipulator is required to follow a pre-established trajectory.

Current present-day manipulators use proportional-derivative controllers (PD) or proportional-integral-derivative controllers (PID) in closed-loop systems in order to reach the desired configurations. For an updated reference on PID controllers, see (Benett, 2001) and (Aström and Hägglund, 2001). It has been proven that PID controllers, despite their widespread use, do not show global asymptotic stability when controlling a robotic manipulator (Wen and Murphy, 1990). Various motion controllers with rigorous stability demonstrations can be found in the literature: (Sciavicco and Siciliano, 2000; Craig, 1989) among others.

The PD controller with gravity compensation produces a global asymptotically stable closed-loop system through a trivial selection of the proportional and derivative gains (Takegaki and Arimoto, 1981). The PD+ controller, introduced by Koditschek (Koditschek, 1984) is both simple and attractive. Its control structure is based on a linear PD feedback loop plus a specific compensation of robot dynamics. The first stability analysis of a PD+ controller was done by Paden and Panja (1988), who termed it PD+ control. Later, Whitcomb *et al.* (1993) present a rigorous stability analysis by introducing a Lyapunov function in an adaptive control context.

The global asymptotic stability analysis of a closed-loop system using the above-cited controllers has been carried out in the above mentioned papers by considering a selected set of constant gains of the controllers. This characteristic may constrain the application of these controllers when, in addition to asymptotic stability, a high performance of the control system is required as well. To have a good performance in manipulator control with actuator constrains implies to implement variable gains in the controllers. Variable-gain PD controllers for position and motion control of manipulators have been implemented in (Kelly and Carelli, 1996) and, recently, Santibañez *et al.* (2000) presented a variable-gain PD+ controller that uses fuzzy logic.

We present here an inverse dynamics controller with non-linear PD gains, which allows for motion and impedance control. It avoids saturation of control actions and improves the performance for small control errors.

The work is organised as follows. Section II describes the model and control scheme along with its stability analysis. The application of a control algorithm to a 3-dof manipulator is presented in Section III, and the conclusions in Section IV.

II. ROBOT MODEL AND CONTROLLER DESIGN

A Robot Model

With no perturbations present, the joint-coordinates dynamic model of a robot manipulator interacting with the environment is:

$$\tau = M(q)\ddot{q} + C(q,\dot{q})\dot{q} + g(q) + \theta(\dot{q}) + J^T(q)f_m \quad (1)$$

where τ is the $n \times 1$ vector of torques or forces applied on the joints, $M(q) \in \Re^{n\times n}$ is the manipulator's inertia matrix that is symmetric and positive definite; $C(q,\dot{q}) \in \Re^{n\times n}$ is the matrix of centrifugal and Coriolis forces; $g(q) \in \Re^n$ is the vector of gravitational torques