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An Inverse Dynamics-Based Discrete-Time Sliding Mode Controller for Robot Manipulators

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12.1 Introduction

In the past years an extensive literature has been devoted to the subject of motion control of rigid robot manipulators. Many approaches have been proposed, such as feedback linearization [1], model predictive control [2], as well as sliding mode or adaptive control [3], [4], [5]. The basic idea of feedback linearization, known in the robotic context as inverse dynamics control [6], [7], is to exactly compensate all the coupling nonlinearities in the dynamical model of the manipulator in a first stage so that a second stage compensator may be designed based on a linear and decoupled plant. Although global feedback linearization is possible in theory, in practice it is difficult to achieve, mainly because the coordinate transformation is a function of the system parameters and, hence, sensitive to uncertainties which arise from joint and link flexibility, frictions, sensor noise, and unknown loads. This is the reason why the inverse dynamics approach is often coupled with robust control methodologies [1].

Among these, a possibility is offered by sliding mode control [8], [9] which is robust versus a significant class of parameter uncertainties and insensitive to load disturbances. Yet, it is a common opinion that the major drawback of sliding mode control applied to robots is the so-called chattering phenomenon due to the high frequency switching of the control signal, which may disrupt or damage actuators, deteriorating the controlled system. Such a phenomenon is increased due to the fact that the sliding mode controller is designed by means of a
continuous-time model for the system to be controlled, but, in practice, input, output, and reference signals are sampled, leading to a discrete-time behavior of the plant. In this way, the control signal is constant during the sampling interval, resulting in finite-time oscillations of the controlled variable [10].

In order to circumvent the chattering problem, many approaches have been followed. In the case of first-order sliding mode control laws, chattering can be circumvented by approximating, with a continuous function, the sign function, but, in this way, only pseudo-sliding modes are generated. By adopting second-order sliding mode control the chattering effect can be made less critical by confining discontinuities to the derivative of the control law [11], [12]. Note that a combination of second-order sliding mode control with the inverse dynamics method has been investigated in [13], while the combination of a first-order pseudo-sliding mode control with compensated inverse dynamics and an adaptive component has been presented in [4].

An alternative way to solve the problem of chattering is that of designing the sliding mode control law directly with reference to the discrete-time system obtained after the sampling procedure [14], [15]. In this paper, a new version of the discrete-time sliding mode control strategy described in [14], combined with the inverse dynamics approach, is proposed to perform motion control of robot manipulators. While in [14] the problem of the presence of uncertainties acting on the plant model is solved by introducing an adaptive term in the control law, in the present case a disturbance estimator is added to the discrete-time sliding mode control law, thus simplifying the approach in presence of input uncertainties.

The proposed control approach has been experimentally verified on the Comau Smart3-S2 industrial robot shown in Fig. 12.1. To this end, a suitable model of the robot has been formulated, and a practical MIMO parameters identification procedure, recently devised [16], has been applied. Experimental tests demonstrate the efficiency and the appreciable tracking performances of the presented inverse dynamics-based discrete-time sliding mode control strategy.

12.2 The Considered Dynamical Model

The dynamical model of an \( n \)-joint robot manipulator can be written in the joint space

\[
u = B(q)\ddot{q} + C(q, \dot{q})\dot{q} + g(q) + F_d\text{sign}(\dot{q}) + F_v\dot{q},
\]  

(12.1)