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Adaptive backstepping control of some uncertain nonlinear oscillators

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***Abstract*— A backstepping-based adaptive controller is designed for a class of uncertain second orded nonlinear systems under the strict-feedback form. It is shown that the closed loop is globally uniformly ultimately bounded and we give explicit bounds on both the asymptotic and transient performance. The control strategy is applied to a system typically found in base isolation schemes for seismic active protection of building structures. This system exhibits a hysteretic nonlinear behavior which is described analytically by the so-called Bouc–Wen model. Unlike other control schemes, the developed backstepping control does not require an exact knowledge of the model parameters. They are only defined within known intervals. The practical effectiveness of the controller is illustrated by numerical simulations.**

I. INTRODUCTION

Backstepping-based control has been proposed in recent years as a powerful method for stabilizing nonlinear systems both for tracking and regulation purposes [1]. The main advantage of these designs is the *systematic* construction of a Lyapunov function for the closed loop, allowing the analysis of its stability properties. The adaptive version of these designs, especially the tuning functions design, offers the possibility to synthetize in a systematic way controllers for a wide class of nonlinear systems (those under the strict-feedback form) whose structure is known but with *unknown* parameters [1]. They also offer the possibility to analyze the transient behavior of the closed loop *in the absence of uncertainties*. Despite the fact that the robustness of the tuning functions design has been studied extensively in the case of linear systems [2], [3], [4], [5], [6], [7], much more is to be done in the case of nonlinear systems [8], [9]. In [10] a robust adaptive scheme for nonlinear systems with globally exponentially stable unmodeled dynamics has been developed for the *regulation* case. For the class of nonlinearities studied in [10] the unmodeled dynamics enter to the system state equations as functions which can be unbounded with respect to the state, but bounded with respect to the time. Despite the fact that the scheme in [10] ensures arbitrary asymptotic performance, it does not allow the quantification of the transient performance as an *explicit* function of the design parameters.

In this paper, we propose a simple backstepping-based adaptive scheme for a class of strict-feedback nonlinear systems for the *tracking* problem. The systems studied in the present paper arise from a class of nonlinear second order oscillators, which are common in structural engineering models of base isolation devices for seismic protection of buildings [11].

The proposed adaptive scheme uses the switching σ-modification [2], [4] and new terms that incorporate part of the information on the uncertainties. The adaptive algorithm allows the quantification of both transient and asymptotic performance as explicit functions of the design parameters. The uncertain nonlinear part of the open loop is written as the sum of the scalar product of -possibly- unknown coefficients with known functions, plus a residual which may be unbounded with respect to the state, but is bounded with respect to the time. This representation has the practical advantage of giving an estimation of the uncertain part by an open loop identification. For structural systems, which are stable in open loop, this is often possible. The reduction of the size of the uncertainty often results in a reduction of the amplitude of the control signal since the nonlinear terms which counteract the effect of the uncertainty are smaller.

In order to test the practical potential of the proposed control scheme, it is applied to design an active controller for a seismic base isolation scheme which has a nonlinear hysteretic behavior. This behavior is described by the so-called Bouc–Wen model [12], which is well accepted in the context of structural mechanics for its ability to describe analytically a wide spectrum of hysteretic loops [13].

Hysteresis is encountered in a wide variety of processes in which the input-output dynamic relations between variables involve memory effects. Examples are found in biology, optics, electronics, ferroelectricity, magnetism, mechanics, structures, among other areas. This paper is primarily concerned with hysteresis in mechanical and structural systems. In these systems, hysteresis appears as a natural mechanism of materials to supply restoring forces against movements and dissipate energy [14]. This mechanism has been exploited in recent years in building damping devices and vibration isolation schemes [15], [16]. In a near context, mechanical and structural hysteresis is also encountered when using new "smart" materials and actuators for vibration control, as the cases of shape memory alloys [17] and electro/magnetorheological fluids [18].

While there is an extensive literature about physical characterization and mathematical modelling of hysteretic systems in different areas, only a few references are found reporting feedback controllers in the general literature on control systems [19], [20], [21], [22]. In structural systems,