

A Time Delay-Based gain Scheduled Control For Electromagnetic Suspension System

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ABSTRACT: This paper proposes a robust gain scheduled control technique using time-delay for the nonlinear systems with model uncertainty and unexpected disturbances. The time-delay-based gain scheduling method depends on a direct estimation of a function representing the effect of uncertainty. The information from the estimation is used to cancel the unexpected disturbances simultaneously. The time-delay-based gain scheduled control uses the past observation of the system's response and the control input to directly modify the control actions rather than to adjust the controller gains or to identify system parameters. The benefits of this proposed scheme are demonstrated in the simulation of an electromagnetic suspension system with model uncertainty and external disturbances, and the method is compared with the conventional state feedback controller.

1 INTRODUCTION

The gain scheduled control technology has been proved to be successful in many engineering applications where the fixed gain control does not produce a satisfactory result (J. HUANG *et al.* 1990, J. HUANG *et al.* 1992, W. J. RUGH 1995, I. KAMINER *et al.* 1992). The method, however, has a limitation that the resulting control system works only for systems with constant parameters or sufficiently slow time-varying parameters, which can be well modeled by some scheduling parameters. Recently, in order to improve the regulation performance for a system with relatively fast time-varying parameters, there is proposed a method that utilizes derivative information (N. SURESHBABU *et al.* 1995, S.-H. LEE *et al.* 1997). Also, there are known a class of control design methods (Y. H. CHEN 1993, M. P. GLAZOS *et al.* 1995, S.-H. LEE *et al.* 1997) in which uncertainty is decomposed into two categories; matched uncertainty and mismatched uncertainty. Further a concept of k th-order approximate equilibrium point is introduced in (J. HUANG *et al.* 1992, J. HUANG 1995), and then its k th-order robust control law is constructed for a class of uncertain nonlinear systems with time-varying parameters. More recently, the H_∞ control has become an effective design methodology for the tracking control problem for uncertain plants in view of stability and robustness. In addition, the fusion of the H_∞ control theory and gain scheduling has been paid a great deal of attention (R. A. NICHOLS *et al.* 1996, P. APKARIAN *et al.* 1995, W. W. LU *et al.* 1995). Especially, it is noted

that H_∞ synthesis technique is extended in (P. APKARIAN *et al.* 1995) to allow the controller to be dependent on time-varying but measurable parameters in linear time-varying systems. Using the H_∞ gain scheduled controller, some robust properties were guaranteed at local operating points.

In many practical situations, however, some parameters of the system are either poorly defined or the system operates in the environments where the parameters change in a non-predictable manner. In such situations, the conventional fixed gain control will be inadequate to achieve a satisfactory performance in the entire range. Several advanced control techniques have been developed for such systems, one of which is the time-delay control (I.H. SUH *et al.* 1979, K. YOUCEF-TOUMI. *et al.* 1990, P. H. CHANG *et al.* 1995, T. C. HSIA *et al.* 1990). In this paper, we propose a robust gain scheduled system consisting of the time-delay control and the gain scheduler for the nonlinear systems with external disturbances and parameter uncertainty. In the proposed time-delay gain scheduling method, the effect of uncertainty is directly estimated and the information from estimation is used to cancel the effect of unknown dynamics and unexpected disturbances simultaneously. Also, the proposed estimation scheme with a finite convergence time is formulated in order to estimate the unknown scheduling variable.

As a possible application, we investigate an electromagnetic suspension system model, which represents the essential dynamics of magnetically levitated transport system. The system is highly

