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Advanced Discrete-Time Control

Designs and Applications

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To my wife Burcu and daughter Nora

Khalid Abidi

*To my wife Iris Chen and daughter
Elizabeth Xu*

Jian-Xin Xu

Preface

This monograph aims to cover a wide spectrum of systems such as linear and nonlinear multivariable systems as well as control problems such as disturbance, uncertainty, and time-delays. The purpose is to provide researchers and practitioners a manual for the design and application of advanced discrete-time controllers.

The monograph presents six different control approaches depending on the type of system and control problem. The first and second approaches are based on Sliding Mode control (SMC) theory and are intended for linear systems with exogenous disturbances. The third and fourth approaches are based on adaptive control theory and are aimed at linear/nonlinear systems with periodically varying parametric uncertainty or systems with input delay. The fifth approach is based on learning control (ILC) theory and is aimed at uncertain linear/nonlinear systems with repeatable tasks and the final approach is based on fuzzy logic control (FLC) and is intended for highly uncertain systems with heuristic control knowledge.

In the presentation of the above control approaches, it is worthwhile highlighting that, unlike in continuous-time problems, robust control approaches characterized by high feedback gain are no longer suitable in discrete-time implementations due to the inherent stability property. As a consequence, low gain profiles are essential in discrete-time control. To meet the control requirement such as precision tracking when model uncertainties are present, it is necessary to explore more subtle or smart control approaches that are based on the underlying characters of system uncertainties.

In this monograph, we first present a disturbance estimation approach together with SMC. By making full use of discrete-time or sampled-data properties, a time-delay-based estimator is constructed to perform disturbance estimation, where the disturbance can be any exogenous uncertain factors. By virtue of the disturbance estimation that works as a kind of universal feed-forward compensation, low gain feedback is sufficient to warrant a precise tracking control performance.

Next, we present adaptive control approaches that can deal with parametric uncertainties. Both time invariant and time varying unknown parameters can be adaptively estimated so that a low feedback gain control can be employed to achieve generic tracking tasks.

Then, we present an iterative learning control approach that can significantly enhance tracking performance as far as the control task repeats. Learning not only from previous control tracking error profiles but also from previous control signals, the effect of system uncertainties, either parameterized or lumped, can be nullified completely when learning repeats iteratively. We particularly present ILC design and property analysis, which assures a monotonic tracking convergence along the iterative horizon. Monotonic tracking convergence is highly desired in practical control problems.

When heuristic control knowledge is available, fuzzy logic control is a suitable approach because it can easily incorporate heuristic knowledge through constructing an appropriate rule base. In this monograph, we present a fuzzy PID controller with a parallel structure, and implement an autotuning scheme according to classical gain and phase margins. In this way, the classical control design is well connected to the advanced FLC.

For each approach presented in the monograph, real-world-based examples are used as case studies to demonstrate the effectiveness and ease of implementation of the designed controllers. First, when introducing each control approach in a chapter, numerical examples are provided to illustrate the controller design guidelines, and the effectiveness of the control approach is compared with classical control methods. Next, we present a benchmark control task: precision control of a piezomotor-driven linear stage. Experimentally, SMC and ILC show excellent tracking performance with the achieved precision at micrometer or sub-micrometer scale. Finally, we apply advanced discrete-time control approaches to four representative engineering control problems, (1) Speed control of PM synchronous motor, a common engineering problem; (2) position control of ball and beam system, a typical motion control task; (3) level control of a coupled tank system, a process control task; and (4) ramp metering control of a freeway traffic system, a large-scale traffic control task.

Singapore, February 2015

Khalid Abidi
Jian-Xin Xu

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