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Iterative Learning Control

Robustness and Monotonic Convergence for Interval Systems

Springer

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This work is dedicated to:

My wife, Min-Hui Kim, and
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– Hyo-Sung Ahn

My family, Tamra, Joshua, and Julia, and
Professor Suguru Arimoto

– Kevin L. Moore

The memory of my father Hanlin Chen, and
My family, Huifang Dou, Duyun, David, and Daniel

– YangQuan Chen

Preface

This monograph studies the design of robust, monotonically-convergent iterative learning controllers for discrete-time systems. Iterative learning control (ILC) is well-recognized as an efficient method that offers significant performance improvement for systems that operate in an iterative or repetitive fashion (e.g., robot arms in manufacturing or batch processes in an industrial setting). Though the fundamentals of ILC design have been well-addressed in the literature, two key problems have been the subject of continuing research activity. First, many ILC design strategies assume nominal knowledge of the system to be controlled. Only recently has a comprehensive approach to robust ILC analysis and design been established to handle the situation where the plant model is uncertain. Second, it is well-known that many ILC algorithms do not produce monotonic convergence, though in applications monotonic convergence can be essential. This monograph addresses these two key problems by providing a unified analysis and design framework for robust, monotonically-convergent ILC.

The particular approach used throughout is to consider ILC design in the iteration domain, rather than in the time domain. Using a lifting technique, the two-dimensional ILC system, which has dynamics in both the time and iteration domains, is transformed into a one-dimensional system, with dynamics only in the iteration domain. The so-called super-vector framework resulting from this transformation is used to analyze both robustness and monotonic convergence for typical uncertainty models, including parametric interval uncertainties, frequency-like uncertainty in the iteration domain, and iteration-domain stochastic uncertainty. For each of these uncertainty models, corresponding ILC design concepts are developed, including optimization-based strategies when the system Markov matrix is subject to interval uncertainties, an algebraic approach to iteration-domain H_∞ control, and iteration-domain Kalman filtering.

Readers of the monograph will learn how parametric interval concepts enable the design of less conservative ILC controllers that ensure monotonic convergence while considering all possible interval model uncertainties. Additionally, by considering H_∞ techniques and Kalman filtering in the iteration domain using the super-vector framework, the notion of ILC baseline error is established analytically, leading the reader to understand the fundamental limitations of ILC.

The monograph is organized into three different parts and an appendix section. In Part I, we provide research motivations and an overview of the literature. This part of the monograph gives an introduction to ILC and introduces the basic robustness and monotonic convergence issues that can arise. A brief summary of the ILC literature is given and the super-vector approach is presented. In Part II, the concept of a parametric interval is used to reduce the conservatism arising in testing the robust stability of traditional robust ILC methods. In this part, Markov vertex matrices are used for analyzing the monotonic convergence of uncertain ILC systems and, based on this analysis, two different synthesis methods are developed to design ILC controllers that provide robust stability for such systems. In addition to analysis and synthesis of ILC laws for interval systems, it is shown how to develop suitable Markov interval models from state-space interval models. In Part III, the concepts of H_∞ ILC, Kalman filter-augmented ILC, iteration-varying robust ILC, and intermittent ILC are developed. In H_∞ ILC, a unified robust framework for handling model uncertainty, iteration-varying disturbances, and stochastic noise is developed. In Kalman filter-augmented ILC, the baseline ILC error is analytically calculated for use in the off-line design of an ILC update algorithm. Next we consider ILC algorithm design for the case of plants with iteration-varying model uncertainty, under the requirement of monotonic convergence. We conclude this part by considering a Kalman filter-based ILC design for the case where the system experiences data dropout. There are four appendices, comprising a taxonomy of ILC literature published since 1998 and three separate studies, each introducing and solving a fundamental interval computation problem: finding the maximum singular value of an interval matrix, determining the robust stability of an interval polynomial matrix, and obtaining the power of an interval matrix. These three solutions are used as basic tools for designing robust ILC controllers.

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Golden, Colorado, USA *Kevin L. Moore*
Logan, Utah, USA *YangQuan Chen*
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Acknowledgments

The purpose of this book is to give a single, unified presentation of our research, based on a series of papers and articles that we have written and on the dissertation of the first author. To achieve this goal, it has been necessary at times to reuse some material that we previously reported in various papers and publications. Although in most instances such material has been modified and rewritten for the monograph, copyright permission from several publishers is acknowledged as follows:

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