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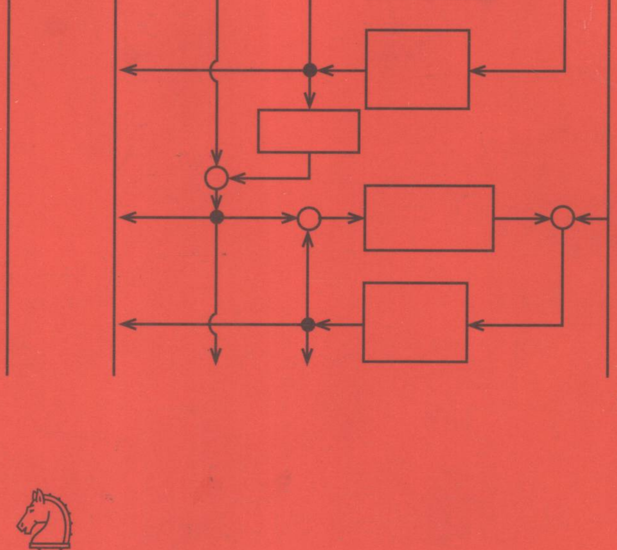
Yangquan Chen and Changyun Wen

Iterative Learning Control

Convergence, Robustness and Applications



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With 69 Figures

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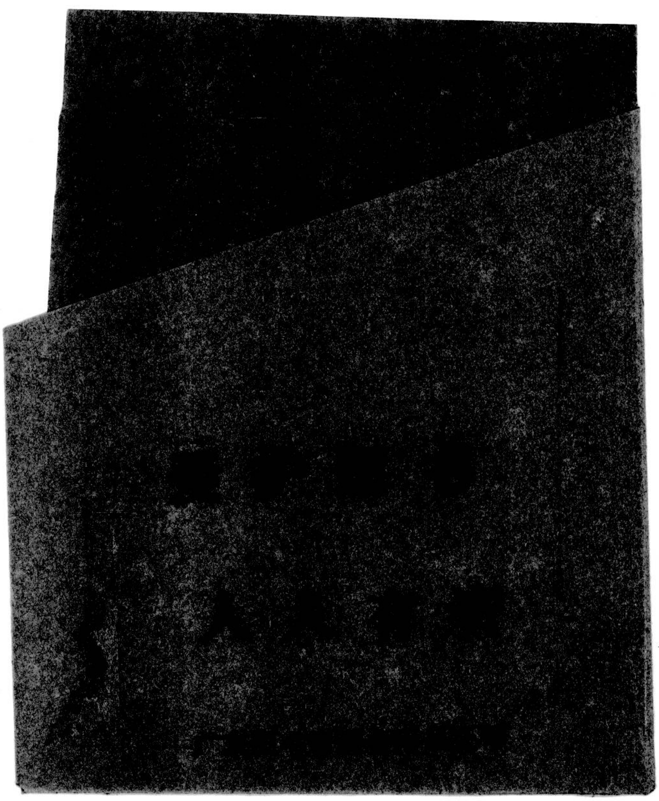

① Intelligent control systems.

② Neural networks (Computer Science)

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This work is dedicated to

Our Parents, and

Huifang Dou and Duyun Chen (Jun Jun)

— Yangquan Chen

Xiu Zhou, Wen Wen, Wendy Wen and Qingyun Wen

— Changyun Wen

Preface

A SYSTEM is called a 'repetitive system' when it performs a given task repeatedly. Robotic and functional neuromuscular stimulation systems are examples of such systems. Iterative Learning Control (ILC), which is a relatively new area in the field of control, is proposed to control these types of systems.

Generally speaking, a system under control may have uncertainties in its dynamic model and its environment. One attractive point in ILC is the utilisation of the system repetitiveness to reduce such uncertainties and in turn to improve the control performance by operating the system repeatedly. ILC is a feedforward control strategy that updates, through iterative learning, control signals at every repeated operation. As the number of iterations increases, the system tracking error over the entire operation time period including the transient portion will decrease and eventually vanish. This may not be possible for conventional non-iterative learning control.

This book provides readers with a comprehensive coverage of iterative learning control and emphasises both theoretical and practical aspects. It provides some recent developments in ILC convergence and robustness analysis as well as issues in the ILC design. These include: *High-order Updating Laws, Discrete-time Domain Analysis, Use of the Current Iteration Tracking Error, Initial State Learning, Terminal Iterative Learning Control, ILC Design via Noncausal Filtering or Local Symmetrical Integral (LSI), Iterative Learning Identification* and so on. Several practical applications are included to illustrate the effectiveness of ILC. These applications include: *Rapid Thermal Processing Chemical Vapor Deposition (RTPCVD) Thickness Control in Wafer Fab Industry, Identification of Aerodynamic Drag Coefficient Curve* and *Trajectory Control in Functional Neuromuscular Stimulation (FNS) Systems.* The application examples provided are particularly useful to readers who wish to capitalise the system repetitiveness to improve system control performance.

The book can be used as a reference or a text for a course at graduate level. It is also suitable for self-study and for industry-oriented courses of continuing education. The knowledge background for this monograph would be some undergraduate and graduate courses including calculus, optimization and nonlinear system control. Some knowledge on optimal control and iteration theory would certainly be helpful. There are 12 chapters in this monograph. Chapter 1 is to give an introduction of ILC with an extended yet brief literature review. The next eight chapters, i.e. Chapters 2 - 9, provide some new theoretical developments in ILC, followed by two chapters on ILC applications. Conclusions are drawn and some recommendations for future research are given in the last chapter. However, the material in each chapter is largely independent so that the chapters may be used in almost any order desired.

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Contents

1. Introduction

1.1 Background

1.1.1 Repetitive Systems

A 'REPETITIVE SYSTEM' is so called when the system performs a given task repeatedly. This kind of systems, also called the 'multi-pass' processes, was first investigated by J. B. Edwards and D. H. Owens [79, 80]. According to [79, 80], a repetitive dynamic system or multi-pass process is a process possessing the following two novel properties:

- *Repetitive action* in which the process repeats an operation by passing an object or information sequentially through the same dynamic machine or process; and
- *Interaction* between the state or output functions generated during successive operations.

Each individual cycle of operation is termed as a 'pass' or an iteration through the system dynamics. Typical examples of multi-pass processes include automatic ploughing, multi-machine systems such as vehicle conveyers, machining of metals and automatic coal cutting. The early research is to explore the new system characteristics and the main interests are in the stability analysis [79, 183, 207]. The interpretation of multi-pass systems in a framework of the 2-D system theory was found in [30, 204].

It is interesting to note some of the research suggestions from [80]:

- The inter-pass control policy clearly allows some potential for optimizing the behavior of successive batches as the pass number n increases [80, page 279].
- Again, of course, feedforward control based on previous-pass histories must be augmented by present-pass control [80, page 280].

However, there is an important feature behind such kind of system which was not emphasized in [80, 207]. That is, the system repetition can be utilized to improve the system performance by revising the controls from pass to pass. Later in [203, 202, 205, 208, 8, 209], this was realized.