

Advances in Industrial Control

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Advances in Industrial Control is a series of monographs and contributed titles focusing on the applications of advanced and novel control methods within applied settings. This series has worldwide distribution to engineers, researchers and libraries.

The series promotes the exchange of information between academia and industry, to which end the books all demonstrate some theoretical aspect of an advanced or new control method and show how it can be applied either in a pilot plant or in some real industrial situation. The books are distinguished by the combination of the type of theory used and the type of application exemplified. Note that “industrial” here has a very broad interpretation; it applies not merely to the processes employed in industrial plants but to systems such as avionics and automotive brakes and drivetrain. This series complements the theoretical and more mathematical approach of Communications and Control Engineering.

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Ying Bai · Zvi S. Roth

Classical and Modern Controls with Microcontrollers

Design, Implementation, and Applications

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*This book is dedicated to my wife, Yan Wang,
and to my daughter, Susan (Xue) Bai.*

Dr. Ying Bai

*I owe everything that I know in Control
Systems to many teachers and colleagues that
I have had over the years. I chose to dedicate
this book to my first teachers from the
Technion, Israel Institute of Technology,
Prof. Julius Preminger and Prof. Eliezer
Schoen, who introduced me to this field and
are responsible for the first spark of interest
that later became a career long passion.
Dr. Preminger later became my M.Sc. thesis
advisor. I worked as a Teaching Assistant for
Dr. Schoen many times and learned a lot
from our weekly planning sessions. The
lecture notes from that period still look fresh
and relevant and I used some of this material
in this book.*

*Dr. Schoen introduced all his students to
dynamic simulations. At that time, in the early
1970s, the tool of choice was the text-based
CSMP. These simulation tools became
lifelong friends.*

Dr. Zvi S. Roth

Series Editor's Foreword

The subject of control systems engineering is viewed very differently by researchers and those that practice the craft. The former group develops general algorithms with a strong underlying mathematical basis while for the latter concerns over the limits of equipment and plant downtime dominate. The series *Advances in Industrial Control* attempts to bridge this divide to some extent and hopes to encourage technology transfer.

The rapid development of new control theory and technology has an impact on all areas of control engineering and applications. There are new control theories, actuators, sensor systems, communication and computing methods, design philosophies, and, of course, new application areas. This provides some justification for a specialized monograph series but there is another more important reason. The development of relevant control theory needs to be stimulated and driven by the needs and challenges of applications. A focus on applications is also essential if the different aspects of the control design problem are to receive sufficient attention.

There is a lot of work on the analysis and synthesis problems in control systems engineering but much less on the problems of control design. The path from a control loop specification to a design, which satisfies requirements is often paved with uncertainties and confusion. The series provides an opportunity for researchers to present an extended exposition of new work on industrial control, raising awareness of the substantial benefits that can accrue, and the challenges that can arise, and dealing with this important issue of control-systems design.

The authors of this text have been working on the subject of control design and implementation over many years, and contributed to the literature in what is a rapidly changing environment. This book is concerned with the technology used when implementing control systems, which is a difficult topic to present when the technology and programming methods change every decade. However, there are some underlying principles that underpin current and probably future systems that the authors have covered. In fact, a good proportion of the material covers control fundamentals but often linked to the practical problems of implementation in digital devices.

The problems of sensor systems, actuators, and numerical implementation in microcomputing devices are often avoided in theoretical studies but this text covers the latter in great detail. At the same time, it provides an overview of some of the most useful tools in classical control theory and covers some topics in model-based and more advanced control. The MATLAB[®] scripts are useful for students and the Homework and Labs sections are valuable for instructors.

This text covers material that is often not considered in the huge volume of papers and books on control engineering. It is, therefore, a welcome addition to the series on *Advances in Industrial Control*.

Glasgow, UK
August 2018

Michael J. Grimble

Preface

Today, the most popular and powerful control technologies applied in our routine life are automatic and intelligent controls. Each individual living in our world, more or less, is under the effects or takes advantages of digital controls. Examples of such control techniques implemented in our society include automobiles, intelligent and graphic calculators, room cleaning robots, washers/dryers, HVAC systems, refrigerators, ATMs, iPads, iPhones, vending machines, and so on. Almost all aspects of our life are affected by either classical or modern control technologies.

In order to catch up, understand and master these control techniques, a complete and solid understanding and study process are necessary to all of us, of course, including college students. A good and practical textbook is prerequisite for this kind of study and learning process.

However, it is very difficult or even impossible to find a good or matched textbook for this objective from the current book market. Most control textbooks just discussed or covered popular control theories with some simulations. These kinds of textbooks cannot enable students to fully understand and apply what they learned to develop real control systems with only theory and simulations experience. A complete and detailed development chain is absolutely necessary to enhance students' learning and understanding abilities about classical and modern industrial control techniques and technology. This is the target objective of this textbook.

The authors of the book tried to provide a fully and completed package to cover both classical and modern control technologies with a real microcontroller system TM4C123GXL. The package includes not only solid theoretical introductions and simulations about traditional and modern control techniques, but also a set of implementation components, which contain the following:

- (1) A powerful and latest microcontroller—TM4C123GH6PM (Texas Instruments),
- (2) A Tiva™ TM4C123GXL LaunchPad™ Evaluation Board (EVB),
- (3) An EduBASE ARM Trainer,
- (4) A Keil® MDK μ Version-5 Integrated Development Environment (IDE)

With the help of these hardware and software as well as practical application notes with real examples, students can design, develop, and build some real and actual control systems by developing practical programming codes to control microcontrollers to perform real time controls to some motor systems. All example projects in the book have been compiled, built, and tested. To help students to master the main techniques and ideas, three appendices are also provided to facilitate the students to overcome some possible learning curves.

In addition to home works attached at each chapter, two sets of practical projects are also involved in this book, Class Projects and Lab Projects, to enable students to effectively learn and build some actual control program for real control systems. A complete set of home work solutions is provided for instructors. Moreover, a set of complete teaching materials built in MS PPT is also provided for instructors to facilitate their teachings.

You are welcome to have any question or comment for this book.

Charlotte, USA
Boca Raton, USA

Dr. Ying Bai
Dr. Zvi S. Roth

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The first and most special thank to Dr. Ying Bai's wife, Yan Wang, and we could not finish this book without her sincerely encouragement and support.

Many thanks should be given to the Editors Oliver Jackson, Meertinus Faber and Subodh Kumar who made this book available to public. You could not find this book from the market without their deep perspective and hard working. The same thanks are extended to the editor team of this book. Without their contributions, it is impossible for this book to be published.

Finally but not the last, the thanks should be forwarded to all people who support us to finish this book.

Dr. Ying Bai

Over my 36 years of academic career at Florida Atlantic University I enjoyed tremendous amount of academic freedom, thanks to the many department chairs and Deans that I have encountered, which allowed me to compile over the years a large portfolio of undergraduate and graduate courses. This helped me a lot in my writing. Much of the contents came from my lecture notes in the courses of Control Systems 1, Control Systems 2, Nonlinear Systems, and Biosystems Modeling and Control.

I was fortunate to have many outstanding students. For many years, I have collected the best students solutions in each of my courses. Much of this material was very helpful for my case studies and for the homework problems with solutions that I selected for this book. Let me gratefully mention the students whose works I have used: Dr. Kasra Vakilinia, Dr. Ivan Bertaska, Claude Lieber MD, Benjamin Coleman, Dennis Estrada, and more.

Last but not least, many thanks to my loving wife Eva, who freed me up from many important chores, so that I could focus on finishing the book, and to my children who showed active interest and encouraged me to go on.

Dr. Zvi S. Roth

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Dr. Roth served as Chair of the EE Department from 1993 to 1997, and from 2005 to 2008 as Director of the State of Florida funded Florida-Israel Institute. Additional research interests that Dr. Roth has developed over the years include Automation Design for Biotechnology, Submicron Analog Electronic Circuits Design, and Modeling of Biological and Physiological Systems. He published over 50 refereed papers in journals and conferences and graduated 9 Ph.Ds.

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