

# Control System Advanced Methods

Edited by

**William S. Levine**

University of Maryland

College Park, MD, USA



**CRC Press**

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the  
Taylor & Francis Group, an **informa** business

# Contents

---

Preface to the Second Edition .....	xiii
Acknowledgments .....	xv
Editorial Board .....	xvii
Editor .....	xix
Contributors .....	xxi

## SECTION I Analysis Methods for MIMO Linear Systems

---

1 Numerical and Computational Issues in Linear Control and System Theory .....	1-1
<i>A.J. Laub, R.V. Patel, and P.M. Van Dooren</i>	
2 Multivariable Poles, Zeros, and Pole-Zero Cancellations .....	2-1
<i>Joel Douglas and Michael Athans</i>	
3 Fundamentals of Linear Time-Varying Systems .....	3-1
<i>Edward W. Kamen</i>	
4 Balanced Realizations, Model Order Reduction, and the Hankel Operator .....	4-1
<i>Jacqueline M.A. Scherpen</i>	
5 Geometric Theory of Linear Systems .....	5-1
<i>Fumio Hamano</i>	
6 Polynomial and Matrix Fraction Descriptions .....	6-1
<i>David F. Delchamps</i>	
7 Robustness Analysis with Real Parametric Uncertainty .....	7-1
<i>Roberto Tempo and Franco Blanchini</i>	
8 MIMO Frequency Response Analysis and the Singular Value Decomposition .....	8-1
<i>Stephen D. Patek and Michael Athans</i>	
9 Stability Robustness to Unstructured Uncertainty for Linear Time Invariant Systems .....	9-1
<i>Alan Chao and Michael Athans</i>	
10 Trade-Offs and Limitations in Feedback Systems .....	10-1
<i>Douglas P. Looze, James S. Freudenberg, Julio H. Braslavsky, and Richard H. Middleton</i>	
11 Modeling Deterministic Uncertainty .....	11-1
<i>Jörg Raisch and Bruce Francis</i>	

## SECTION II Kalman Filter and Observers

---

12	Linear Systems and White Noise .....	12-1
	<i>William S. Levine</i>	
13	Kalman Filtering .....	13-1
	<i>Michael Athans</i>	
14	Riccati Equations and Their Solution .....	14-1
	<i>Vladimír Kučera</i>	
15	Observers .....	15-1
	<i>Bernard Friedland</i>	

## SECTION III Design Methods for MIMO LTI Systems

---

16	Eigenstructure Assignment .....	16-1
	<i>Kenneth M. Sobel, Eliezer Y. Shapiro, and Albert N. Andry, Jr.</i>	
17	Linear Quadratic Regulator Control .....	17-1
	<i>Leonard Lublin and Michael Athans</i>	
18	$\mathcal{H}_2$ (LQG) and $\mathcal{H}_\infty$ Control .....	18-1
	<i>Leonard Lublin, Simon Grocott, and Michael Athans</i>	
19	$\ell_1$ Robust Control: Theory, Computation, and Design .....	19-1
	<i>Munther A. Dahleh</i>	
20	The Structured Singular Value ( $\mu$ ) Framework .....	20-1
	<i>Gary J. Balas and Andy Packard</i>	
21	Algebraic Design Methods .....	21-1
	<i>Vladimír Kučera</i>	
22	Quantitative Feedback Theory (QFT) Technique .....	22-1
	<i>Constantine H. Houppis</i>	
23	Robust Servomechanism Problem .....	23-1
	<i>Edward J. Davison</i>	
24	Linear Matrix Inequalities in Control .....	24-1
	<i>Carsten Scherer and Siep Weiland</i>	
25	Optimal Control .....	25-1
	<i>Frank L. Lewis</i>	
26	Decentralized Control .....	26-1
	<i>M.E. Sezer and D.D. Šiljak</i>	
27	Decoupling .....	27-1
	<i>Trevor Williams and Panos J. Antsaklis</i>	
28	Linear Model Predictive Control in the Process Industries .....	28-1
	<i>Jay H. Lee and Manfred Morari</i>	

## SECTION IV Analysis and Design of Hybrid Systems

---

- 29 Computation of Reach Sets for Dynamical Systems ..... 29-1  
*Alex A. Kurzhanskiy and Pravin Varaiya*
- 30 Hybrid Dynamical Systems: Stability and Stabilization ..... 30-1  
*Hai Lin and Panos J. Antsaklis*
- 31 Optimal Control of Switching Systems via Embedding into Continuous  
 Optimal Control Problem ..... 31-1  
*Sorin Bengea, Kasemsak Uthaichana, Milos Žefran, and Raymond A. DeCarlo*

## SECTION V Adaptive Control

---

- 32 Automatic Tuning of PID Controllers ..... 32-1  
*Tore Hägglund and Karl J. Åström*
- 33 Self-Tuning Control ..... 33-1  
*David W. Clarke*
- 34 Model Reference Adaptive Control ..... 34-1  
*Petros Ioannou*
- 35 Robust Adaptive Control ..... 35-1  
*Petros Ioannou and Simone Baldi*
- 36 Iterative Learning Control ..... 36-1  
*Douglas A. Bristow, Kira L. Barton, and Andrew G. Alleyne*

## SECTION VI Analysis and Design of Nonlinear Systems

---

- 37 Nonlinear Zero Dynamics ..... 37-1  
*Alberto Isidori and Christopher I. Byrnes*
- 38 The Lie Bracket and Control ..... 38-1  
*V. Jurdjevic*
- 39 Two Timescale and Averaging Methods ..... 39-1  
*Hassan K. Khalil*
- 40 Volterra and Fliess Series Expansions for Nonlinear Systems ..... 40-1  
*Françoise Lamnabhi-Lagarrigue*
- 41 Integral Quadratic Constraints ..... 41-1  
*Alexandre Megretski, Ulf T. Jönsson, Chung-Yao Kao, and Anders Rantzer*
- 42 Control of Nonholonomic and Underactuated Systems ..... 42-1  
*Kevin M. Lynch, Anthony M. Bloch, Sergey V. Drakunov, Mahmut Reyhanoglu,  
 and Dmitry Zenkov*

## SECTION VII Stability

---

- 43 Lyapunov Stability ..... 43-1  
*Hassan K. Khalil*
- 44 Input–Output Stability ..... 44-1  
*A.R. Teel, T.T. Georgiou, L. Praly, and Eduardo D. Sontag*
- 45 Input-to-State Stability ..... 45-1  
*Eduardo D. Sontag*

## SECTION VIII Design

---

- 46 Feedback Linearization of Nonlinear Systems ..... 46-1  
*Alberto Isidori and Maria Domenica Di Benedetto*
- 47 The Steady-State Behavior of a Nonlinear System ..... 47-1  
*Alberto Isidori and Christopher I. Byrnes*
- 48 Nonlinear Output Regulation ..... 48-1  
*Alberto Isidori and Lorenzo Marconi*
- 49 Lyapunov Design ..... 49-1  
*Randy A. Freeman and Petar V. Kokotović*
- 50 Variable Structure, Sliding-Mode Controller Design ..... 50-1  
*Raymond A. DeCarlo, S.H. Zak, and Sergey V. Drakunov*
- 51 Control of Bifurcations and Chaos ..... 51-1  
*Eyad H. Abed, Hua O. Wang, and Alberto Tesi*
- 52 Open-Loop Control Using Oscillatory Inputs ..... 52-1  
*J. Baillieul and B. Lehman*
- 53 Adaptive Nonlinear Control ..... 53-1  
*Miroslav Krstić and Petar V. Kokotović*
- 54 Intelligent Control ..... 54-1  
*Kevin M. Passino*
- 55 Fuzzy Control ..... 55-1  
*Kevin M. Passino and Stephen Yurkovich*
- 56 Neural Control ..... 56-1  
*Marios M. Polycarpou and Jay A. Farrell*

## SECTION IX System Identification

---

- 57 System Identification ..... 57-1  
*Lennart Ljung*

## SECTION X Stochastic Control

---

- 58 Discrete Time Markov Processes.....58-1  
*Adam Shwartz*
- 59 Stochastic Differential Equations.....59-1  
*John A. Gubner*
- 60 Linear Stochastic Input–Output Models .....60-1  
*Torsten Söderström*
- 61 Dynamic Programming.....61-1  
*P.R. Kumar*
- 62 Approximate Dynamic Programming.....62-1  
*Draguna Vrabie and Frank L. Lewis*
- 63 Stability of Stochastic Systems.....63-1  
*Kenneth A. Loparo*
- 64 Stochastic Adaptive Control for Continuous-Time Linear Systems.....64-1  
*T.E. Duncan and B. Pasik-Duncan*
- 65 Probabilistic and Randomized Tools for Control Design .....65-1  
*Fabrizio Dabbene and Roberto Tempo*
- 66 Stabilization of Stochastic Nonlinear Continuous-Time Systems .....66-1  
*Miroslav Krstić and Shu-Jun Liu*

## SECTION XI Control of Distributed Parameter Systems

---

- 67 Control of Systems Governed by Partial Differential Equations.....67-1  
*Kirsten Morris*
- 68 Controllability of Thin Elastic Beams and Plates.....68-1  
*J.E. Lagnese and G. Leugering*
- 69 Control of the Heat Equation.....69-1  
*Thomas I. Seidman*
- 70 Observability of Linear Distributed-Parameter Systems .....70-1  
*David L. Russell*
- 71 Boundary Control of PDEs: The Backstepping Approach .....71-1  
*Miroslav Krstić and Andrey Smyshlyaev*
- 72 Stabilization of Fluid Flows.....72-1  
*Miroslav Krstić and Rafael Vazquez*

## SECTION XII Networks and Networked Controls

---

- 73 Control over Digital Networks.....73-1  
*Nuno C. Martins*

74 Decentralized Control and Algebraic Approaches.....74-1  
*Michael C. Rotkowitz*

75 Estimation and Control across Analog Erasure Channels ..... 75-1  
*Vijay Gupta*

76 Passivity Approach to Network Stability Analysis and Distributed  
Control Synthesis .....76-1  
*Murat Arcak*

**Index.....Index-1**