Contents

1 Introduction 1
Romain Postoyan, Paolo Frasca, Elena Panteley, and Luca Zaccarian
References 3

Part I Networked Systems: Control and Estimation

2 Contracting Infinite-Gain Margin Feedback and Synchronization of Nonlinear Systems 7
Daniele Astolfi and Vincent Andrieu
2.1 Introduction 7
2.2 Preliminaries 8
2.2.1 Notation 8
2.2.2 Highlights on Graph Theory 9
2.2.3 Problem Statement 10
2.2.4 From Linear to Nonlinear Synchronization 11
2.3 Robust Contractive Feedback Design 12
2.3.1 Riemannian Contraction Conditions for δISS 12
2.3.2 Infinite-Gain Margin Laws 15
2.3.3 New Relaxed Conditions for Infinite-Gain Margin Laws 16
2.4 Synchronization of Nonlinear Systems 18
2.4.1 Undirected Graphs and Killing Vector Condition 18
2.4.2 Synchronization of Two Agents with Relaxed Killing Conditions 19
2.4.3 Synchronization with Directed Connected Graphs 21
2.5 Illustration 22
2.6 Conclusions and Perspective 24
References 25

3 Physics-Based Output-Feedback Consensus-Formation Control of Networked Autonomous Vehicles 27
Antonio Loría, Emmanuel Nuño, Elena Panteley, and Esteban Restrepo
3.1 Introduction 28
3.2 Model and Problem Formulation 29
3.2.1 Single-Robot Model 29
3.2.2 The Consensus-Formation Problem 31
3.3 Control Architecture: State-Feedback Case 33
3.3.1 Consensus Control of Second-Order Systems 33
3.3.2 State-Feedback Consensus Control of Nonholonomic Vehicles 36
3.4 Control Architecture: Output-Feedback Case 41
3.4.1 Output-Feedback Orientation Consensus 41
3.4.2 Output-Feedback Position Consensus 44
3.5 Output-Feedback Control Under Delays 46
3.6 An Illustrative Case-Study 49
3.7 Conclusions 55
References 58

4 Relating the Network Graphs of State-Space Representations to Granger Causality Conditions 61
Mónika Józsa, Mihály Petreczky, and M. Kanat Camlibel
4.1 Introduction 62
4.2 Granger Causality and Network Graph of sLTI-SSs 66
4.2.1 Technical Preliminaries: Linear Stochastic Realization Theory 66
4.2.2 Classical Granger Causality and sLTI-SS in Block Triangular Form 70
4.2.3 Conditional Granger Causality and sLTI-SS in Coordinated Form 72
4.2.4 Granger Causality Relations and Directed Acyclic Network Graphs 75
4.2.5 Applications of the Theoretical Results 79
4.3 GB-Granger Causality and Network Graph of GBSs 79
4.3.1 Technical Preliminaries: GBS Realization Theory 79
4.3.2 Extending Granger Causality 84
4.3.3 GB-Granger Causality and Network Graph of GBSs 86
4.4 Conclusions and Future Work 88
References 88

Part II Hybrid Techniques

5 Multi-consensus Problems in Hybrid Multi-agent Systems 93
Andrea Cristofaro, Francesco D'Orazio, Lorenzo Govoni, and Mattia Mattioni
5.1 Introduction 93
5.2 Review on Continuous-Time Systems over Networks 95
5.2.1 Directed Graph Laplacians and Almost Equitable Partitions 95
5.2.2 Multi-consensus of Continuous-Time Integrators 96
5.3 Hybrid Multi-agent Systems 98
5.4 The Hybrid Network Consensus Problem 100
5.4.1 The Multi-consensus Clusters 100
5.4.2 Convergence Analysis 102
5.5 The Hybrid Dynamics Consensus Problem 103
5.5.1 The Hybrid Multi-consensus Dynamics 105
5.5.2 The Hybrid Coupling Design 107
5.6 Application to Formation Control of a Heterogeneous Multi-robot System 108
5.7 Toward Future Perspectives: The Example of Rendezvous of Nonholonomic Robots with Heterogeneous Sensors 110
5.8 Conclusions 113
References 113

6 Observer Design for Hybrid Systems with Linear Maps and Known Jump Times 115
Gia Quoc Bao Tran, Pauline Bernard, and Lorenzo Marconi
6.1 Introduction 115
6.2 Detectability and Observability Analysis 118
6.2.1 Hybrid Observability Gramian 120
6.2.2 Observability Decomposition 124
6.2.3 Observability from y_c During Flows 125
6.2.4 Detectability Analysis 128
6.3 LMI-Based Observer Design from Discrete Quadratic Detectability in Observability Decomposition 133
6.3.1 LMI-Based Observer Design in the z-Coordinates 133
6.3.2 LMI-Based Observer Design in the x-Coordinates 136
6.4 KKL-Based Observer Design from Discrete Uniform Backward Distinguishability in Observability Decomposition 140
6.4.1 Discrete KKL Observer Design for (6.32) 140
6.4.2 KKL-Based Observer Design for (6.26) 143
6.4.3 KKL-Based Observer Design in the (z_o, z_{no})-Coordinates 147
6.4.4 KKL-Based Observer Design in the x-Coordinates 149
6.5 Conclusion 152

6.6 Appendix: Technical Lemmas 154
6.6.1 Exponential Stability of the Error Dynamics 154
6.6.2 Boundedness in Finite Time 158
References 158

7 A Joint Spectral Radius for ω-Regular Language-Driven Switched Linear Systems 161
Georges Aazan, Antoine Girard, Paolo Mason, and Luca Greco
7.1 Introduction 162
7.2 Switched Linear Systems Driven by ω-Regular Languages 163
7.2.1 Deterministic Büchi Automaton 163
7.2.2 Switched Linear Systems 166
7.3 ω-Regular Joint Spectral Radius 167
7.4 ω-Regular Language-Driven Switched Systems and ρ-ω-RJSR 169
7.5 Computing Upper Bounds of the ρ-ω-RJSR 172
7.6 Numerical Example 173
7.7 Conclusion 177
References 178

8 Control of Uncertain Nonlinear Fully Linearizable Systems 179
Sophie Tarbouriech, Christophe Prieur, Isabelle Queinnec, Luca Zaccarian, and Germain Garcia
8.1 Introduction 180
8.2 The Proposed Hybrid Control Scheme 181
8.3 Hybrid Loop Design for Robustness in the Small 183
8.4 Hybrid Loop Design for Robustness in the Large 187
8.5 Numerical Illustration 192
8.5.1 Implementation 192
8.5.2 Example 193
8.6 Conclusion 195
References 196

9 Improved Synthesis of Saturating Sampled-Data Control Laws for Linear Plants 199
Arthur Scolari Fagundes, João Manoel Gomes da Silva Jr., and Marc Jungers
9.1 Introduction 199
9.2 Problem Formulation 201
9.3 Preliminaries 202
9.3.1 Stability of Hybrid Systems 202
9.3.2 Stability Analysis with Saturation 204
9.4 Synthesis of Stabilizing Controller 205
9.5 Polynomial Timer-Dependent Lyapunov Function 208
9.6 Optimization Problems 210
9.7 Numerical Examples 211

9.8 Concluding Remarks 213
References 214

Part III Emerging Trends and Approaches for Analysis and Design

10 Trends and Questions in Open Multi-agent Systems 219
Renato Vizuete, Charles Monnoyer de Galland, Paolo Frasca, Elena Panteley, and Julien M. Hendrickx
10.1 Introduction 219
10.2 Illustrative Examples 222
10.2.1 Consensus 222
10.2.2 Opinion Dynamics 223
10.2.3 Epidemics 224
10.3 Modeling OMAS 226
10.3.1 Modeling Arrivals and Departures 226
10.3.2 Initial State of New Agents 230
10.3.3 Modeling Time Evolution 231
10.4 Analysis of OMAS 234
10.4.1 Definition of Trajectories 234
10.4.2 Stability and Convergence 235
10.4.3 Scale-Independent Quantities 236
10.5 Towards Algorithm Design in OMAS 238
10.5.1 Different Types of Objectives in OMAS 239
10.5.2 Fundamental Performance Limitations 242
10.6 Further Applications 243
10.6.1 Consensus 243
10.6.2 Distributed Optimization and Learning 244
10.6.3 Vehicles and Robots 245
10.7 Future Work 246
10.8 Conclusions 248
References 248

11 Layers Update of Neural Network Control via Event-Triggering Mechanism 253
Sophie Tarbouriech, Carla De Souza, and Antoine Girard
11.1 Introduction 254
11.2 Modeling and Problem Statement 255
11.2.1 Model Description 255
11.2.2 Preliminary Model Analysis 257
11.2.3 Event-Triggering Mechanism 259
11.3 LMI-Based Design of ETM 260
11.3.1 Activation Functions as Quadratic Constraints 260
11.3.2 Sufficient Conditions for Stability 262
11.3.3 Optimization Procedure 266
11.4 Simulations 266

11.5 Conclusion 270
References 271

12 Data-Driven Stabilization of Nonlinear Systems via Taylor's Expansion 273
Meichen Guo, Claudio De Persis, and Pietro Tesi
12.1 Introduction 273
12.2 Data-Driven Nonlinear Stabilization Problem 276
12.3 Data-Based Feasible Sets of Dynamics 277
12.4 Data-Driven Controller Design 280
12.5 RoA Estimation 283
12.5.1 Continuous-Time Systems 285
12.5.2 Discrete-Time Systems 286
12.6 Example 288
12.6.1 Continuous-Time Systems 288
12.6.2 Discrete-Time Systems 289
12.7 Summary 291
12.8 Appendix 291
12.8.1 Petersen's Lemma 291
12.8.2 Proof of Lemma 12.5.3 291
12.8.3 Proof of Lemma 12.5.6 292
12.8.4 Sum of Squares Relaxation 294
12.8.5 Positivstellensatz 294
12.8.6 Proof of Lemma 12.5.8 296
12.8.7 Dynamics Used for Data Generation in the Example 297
References 298

13 Harmonic Modeling and Control 301
Flora Vernerey, Pierre Riedinger, and Jamal Daafouz
13.1 Introduction 301
13.2 Preliminaries 302
13.2.1 Toeplitz Block Matrices 302
13.2.2 Sliding Fourier Decomposition 305
13.3 Harmonic Modeling 305
13.3.1 Harmonic Control and Pole Placement 311
13.3.2 Solving Harmonic Sylvester Equation 315
13.4 Illustrative Example 316
13.5 Conclusion 320
13.6 Appendix 320
References 322

Index 325