

Contents

1	Introduction	1
	María Guinaldo, Francisco R. Rubio, Sebastián Dormido, Pablo Millán, Carlos Vivas and Luis Orihuela	
1.1	Historical Perspective: From Digital Control to Networked Control Systems	1
1.2	Overview of Networked Control Systems and Asynchronous Systems	3
1.2.1	Emergence and Advantages of Networked Control Systems	3
1.2.2	Communication Drawbacks	4
1.2.3	Research Trends	6
1.2.4	Asynchronous Control	8
1.3	Applications and Industrial Technology Over Network	9
1.4	Networked Schemes: From Centralized to Distributed Techniques	13
1.4.1	Centralized and Decentralized Schemes	13
1.4.2	The Middle Ground: Distributed Systems	16
1.5	Communication Through a Non-reliable Network	18
1.6	Asynchronous Control in NCSs	20
1.6.1	Event-Based Control Approaches in the Literature	20
1.6.2	Event Definitions	23
1.7	Stability and Performance Measurements	25

Part I Asynchronous Control for Single-Loop Schemes. Centralized Solutions

2	Send-on-Delta PI Control	29
	Jesús Chacón, José Sánchez and Antonio Visioli	
2.1	Introduction	29
2.2	The LTI and SOD Sampler Blocks	30

2.2.1	The Nonlinear Block: The SOD Sampler	31
2.2.2	The Linear Blocks: The Process and the Controller . . .	32
2.2.3	The P, I, PI, PD, and PID Controllers	36
2.3	Defining an Event-Based System as a PLS.	38
2.3.1	Local Stability	43
2.4	Analysis of the Limit Cycles	44
2.4.1	Equilibrium Points	45
2.4.2	Algorithm	46
2.4.3	Examples of Analysis	47
2.4.4	Implementation in MATLAB [®]	51
2.5	Simulation Results	53
2.5.1	PI-IPTD-SOD _n and PI-SOD _n -IPTD	53
2.5.2	PI-SOPTD-SOD _n	55
2.6	Experimental Results	56
2.6.1	The Acurex System	57
2.6.2	The Model	57
2.6.3	Implementation	58
2.7	Conclusions	62
3	Self-triggered Sampling Selection Based on Quadratic Programming	63
	Luis Orihuela, Pablo Millán and David Muñoz de la Peña	
3.1	Introduction	63
3.2	Problem Formulation	64
3.2.1	Plant Description	64
3.2.2	Model-Based Controller	64
3.3	Lyapunov-Based Sampling Procedure	66
3.3.1	Main Idea and Stability Analysis	66
3.3.2	Algorithm to Select the Following Sampling Time . . .	67
3.3.3	Quadratic Programming Problem	68
3.4	Extension to Continuous Systems	69
3.5	Simulation Results	73
3.5.1	Discrete System	73
3.5.2	Continuous System	75
3.6	Conclusions	77
4	Event-Triggered Anticipative Control over Packet-Based Networks	79
	José Sánchez, María Guinaldo and Sebastián Dormido	
4.1	Introduction	79
4.2	Event-Based Anticipative Control Design	81
4.2.1	Problem Statement	81
4.2.2	Control and Architecture Design	83

4.3	Stability Analysis	86
4.3.1	Analysis of the Maximum RTT and the Model Uncertainties	88
4.3.2	Analysis of the Error Bounds	90
4.4	Disturbance Estimator	91
4.4.1	Stability Analysis	94
4.5	Output-Based Event-Triggered Control	95
4.5.1	Stability Analysis	98
4.5.2	PI Anticipative Control Design	100
4.6	Experimental Results	101
4.6.1	Experimental Framework	101
4.6.2	Performance of Event-Triggered Control	102
4.6.3	Response to Disturbances	105
4.6.4	PI Anticipative Control	107
4.6.5	Network: Delays and Packet Losses	108
4.7	Conclusions	110
5	H_2/H_∞ Control for Networked Control Systems with Asynchronous Communication	111
	Luis Orihuela and Carlos Vivas	
5.1	Introduction	111
5.2	System Description	113
5.2.1	Network Conditions	114
5.2.2	Problem Statement	116
5.3	General Solution for the Suboptimal Mixed H_2/H_∞ Control Problem	116
5.4	Application to Networked Control Systems	119
5.4.1	Lyapunov–Krasovskii Functional	119
5.4.2	Design Method	121
5.5	Event-Based Control Implementation	123
5.5.1	Proposed Approach	123
5.5.2	Remodeling the Node Dynamics	124
5.5.3	Practical Stability for Delayed Asynchronous Systems	125
5.6	Simulation Results	127
5.6.1	Example A	127
5.6.2	Example B	129
5.7	Conclusions	131
6	Asynchronous Packetized Model Predictive Control	133
	Isabel Jurado and Pablo Millán	
6.1	Introduction	133
6.2	Networked Predictive Control Algorithm	134
6.2.1	Problem Setup	134

6.2.2	Packetized Control and Buffering Strategy	135
6.2.3	State Estimator Description	138
6.2.4	Stability Considerations	138
6.3	Application Example	140
6.3.1	Modeling	140
6.3.2	Results.	141
6.4	Conclusions	145

Part II Asynchronous Control and Estimation for Large-Scale Plants. Distributed Solutions

7	Distributed Event-Based Control for Interconnected Linear Systems	149
	María Guinaldo, Dimos V. Dimarogonas, Daniel Lehmann and Karl H. Johansson	
7.1	Introduction	149
7.2	Background and Problem Statement	150
7.2.1	Matrix and Perturbations Analysis	150
7.2.2	Problem Statement	153
7.3	Event-Based Control Strategy	155
7.4	Performance Analysis	157
7.4.1	Perfect and Non-perfect Decoupling	157
7.4.2	Comparison with Other Triggering Mechanisms	160
7.4.3	Simulation Example	162
7.5	Extension to Discrete-Time Systems	164
7.5.1	System Description	164
7.5.2	Discrete-Time Trigger Functions	165
7.5.3	Stability Analysis	165
7.6	Improvements	167
7.6.1	Reducing Actuation in Distributed Control Systems	168
7.6.2	Model-Based Design	176
7.7	Conclusions	179
8	Distributed Event-Based Observers for LTI Systems	181
	Pablo Millán, Carlos Vivas and Carlo Fischione	
8.1	Introduction	181
8.2	Problem Statement	183
8.3	Observer Design	184
8.3.1	Periodic Case	184
8.3.2	Event-Based Implementation	186
8.4	Illustrative Example	189
8.5	Conclusions	191

9	Suboptimal Distributed Control and Estimation: Application to a Four Coupled Tanks System.	193
	Francisco R. Rubio, Karl H. Johansson and Dimos V. Dimarogonas	
9.1	Introduction	193
9.2	System Description: Initial Considerations	195
9.2.1	Plant	195
9.2.2	Network.	196
9.2.3	Agents.	197
9.3	Problem Formulation	198
9.4	Periodic Sampling Case	199
9.4.1	Dynamics of the State and Estimation Error	199
9.4.2	Controller and Observer Design	201
9.5	Event-Based Sampling Case	204
9.5.1	Triggering Rule	205
9.5.2	Remodeling the System Dynamics	205
9.5.3	Stability and Trade-off Between Communication Reduction and Final Boundedness.	207
9.6	Application Example	211
9.6.1	Plant Description.	211
9.6.2	Plant Modeling	213
9.6.3	Experimental Results	215
9.7	Summary	220
10	Distributed Event-Based Control for Non-reliable Networks	223
	María Guinaldo, Daniel Lehmann and José Sánchez	
10.1	Introduction	223
10.2	Problem Statement: Ideal Versus Non-ideal Networks	224
10.3	Transmission Protocol	225
10.3.1	WfA Protocol	226
10.3.2	UwR Protocol.	226
10.4	Performance Analysis for Perfect Decoupling	228
10.4.1	Properties of Deadband Control Using WfA Protocol	228
10.4.2	Properties of Deadband Control Using UwR Protocol	230
10.4.3	Pure Exponential Trigger Functions.	231
10.5	Performance Analysis for Non-perfect Decoupling	234
10.5.1	Solving the State Inconsistency.	235
10.6	Simulation Results	238
10.6.1	Performance	238
10.6.2	Exponential Trigger Functions	239
10.7	Conclusions	240

11 Distributed Estimation in Networked Systems	241
Francisco R. Rubio, Luis Orihuela and Carlos Vivas	
11.1 Introduction	241
11.2 Problem Description and Motivation	242
11.2.1 Network Topology	244
11.2.2 System Description	244
11.3 Periodic Time-Driven Communication Between Agents	245
11.3.1 Agent Dynamics	245
11.3.2 Observer Design	248
11.4 Event-Based Communication Between Agents	249
11.4.1 Remodeling of the Observer Dynamics	249
11.4.2 Practical Stability for Delayed Asynchronous Systems	252
11.5 Simulation Results	253
11.6 Conclusions	256
12 Networked Mobile Robots: An Application Example of the Distributed Event-Based Control	257
Gonzalo Farias, María Guinaldo and Sebastián Dormido	
12.1 Introduction	257
12.2 Formation Control for Networked Mobile Robots	258
12.2.1 Multi-agent Systems and the Consensus Problem	259
12.2.2 Formation Control	261
12.2.3 Model of Non-holonomic Mobile Robots	262
12.2.4 Time-Schedule Control	265
12.2.5 Robot Wireless Communication Protocols	266
12.3 Interactive Simulation Tools	267
12.3.1 Existing Tools	268
12.3.2 Description of the GUI	269
12.3.3 Modeling a Multi-agent System in EJS	270
12.3.4 Using the Simulator	274
12.4 Application Example to a Real Test bed	279
12.4.1 Experimental Framework	279
12.4.2 Experimental Results	281
12.5 Conclusions	287
13 Conclusions	289
María Guinaldo, Pablo Millán and Luis Orihuela	
13.1 Summary of the Book	289
13.2 Comparison Between the Different Solutions	290
13.3 Concluding Remarks	292

Appendix A: Proofs	293
Appendix B: Dealing with Nonlinear Terms in Matrix Inequalities . . .	317
References	321
Index	335

<http://www.springer.com/978-3-319-21298-2>

Asynchronous Control for Networked Systems

Guinaldo Losada, M.; Rodríguez Rubio, F.; Dormido, S.

(Eds.)

2015, XXIV, 339 p. 127 illus., 102 illus. in color.,

Hardcover

ISBN: 978-3-319-21298-2