

Contents

Abstract	xi
1 Introduction	1
1.1 Invariance	4
1.2 Sliding modes	6
1.2.1 Description of the sliding mode	7
1.2.2 Sliding mode existence necessary condition	8
1.2.3 Equivalent control method	11
1.2.4 A necessary and sufficient condition for existence of Sliding Mode	11
1.2.5 Discontinuous Control Action in Sliding Mode Con- trol. Chattering Problem	12
1.3 Sliding Mode Reference Conditioning	13
1.4 Higher Order Sliding Mode	15
1.4.1 Sliding Mode order	16
1.4.2 Regularity conditions	16
1.4.3 Convergence time	16
1.4.4 Second Order Sliding Mode	17
1.5 SM Continuous approximation and Relative degree 2	19
1.6 Motivation	19
1.6.1 Coordination and interconnected systems	19
1.6.2 Estimation in Bioprocesses	20
1.6.3 Control theory in synthetic biology	21
1.7 Scope and objectives	21
1.8 Thesis outline	22
1.9 Publications	25

I	Coordination of dynamical systems	29
2	Coordinación de sistemas dinámicos	31
2.1	Introducción	32
2.2	Coordinación de sistemas	34
2.2.1	Presentación del problema	34
2.2.2	Intercambio de información entre sistemas	35
2.2.3	Suposiciones y definiciones generales	36
2.3	Invarianza y Acondicionamiento de Referencia por MD	37
2.3.1	Invarianza geométrica de conjuntos	38
2.3.2	Acondicionamiento de referencia por MD	41
2.4	Topología global tipo supervisor	44
2.4.1	Esquema propuesto de coordinación	44
2.4.2	Función χ : el mínimo	47
2.5	Topología local distribuida	47
2.6	Simulaciones	51
2.6.1	Topología Global	52
2.6.2	Topología local	54
2.7	Conclusión	58
3	SMRCoord of constrained feedback systems	59
3.1	Introduction	60
3.2	Problem statement	62
3.2.1	Information exchange	63
3.2.2	Constrained systems	64
3.2.3	Assumptions and definitions	64
3.3	Geometric set invariance and sliding mode reference conditioning	64
3.3.1	Geometric set invariance	65
3.3.2	Sliding mode reference conditioning	66
3.4	Reference coordination under local topology	68
3.5	Reference coordination under global topology	71
3.6	Simulation	73
3.6.1	Quadrotors and controllers	75
3.6.2	Information exchange in SMRCoord	75
3.6.3	Simulation results	75
3.7	Conclusion	77

4	UAV reference conditioning for formation control	79
4.1	Introduction	80
4.2	Problem Statement	82
4.3	Formation control	83
4.3.1	Proposed coordination scheme.	83
4.3.2	SMRC analysis and design.	83
4.3.3	Switching frequency and chattering.	85
4.4	Simulation	86
4.4.1	Quadrotors and controllers	86
4.4.2	Virtual leader reference and formation structure	86
4.4.3	Simulation results	86
4.5	Conclusion	88
II	Bioprocesses and sliding modes estimation	91
5	Specific growth rate estimation in (fed-)batch bioreactors using second-order sliding observers	93
5.1	Introduction	94
5.2	Problem formulation and background material	96
5.2.1	Main assumptions	97
5.2.2	Preliminaries	97
5.3	Second-order sliding mode observer	99
5.4	Simulation results	104
5.5	Experimental results	110
5.6	Conclusions	111
6	Stability preserving maps for finite-time convergence	113
6.1	Introduction	114
6.2	Motivation	116
6.2.1	Super-twisting algorithm	116
6.2.2	Preliminary analysis of the super-twisting algorithm.	117
6.3	Constructive design of the super-twisting algorithm.	119
6.3.1	Case $r(z_1) \equiv 0$	122
6.3.2	Case $r(z_1) \neq 0$	123
6.4	Stability analysis	127
6.5	Finite-time convergence	132

6.6	Example	133
6.7	Conclusions	135
7	Second-Order Sliding Mode Observer for Multiple Kinetic Rates Estimation in Bioprocesses	139
7.1	Introduction	140
7.2	Bioprocess model and problem statement	142
7.3	A Second-order Observer of Specific Kinetic Rates	144
7.3.1	Definitions	144
7.3.2	Main result	145
7.4	Experimental results	149
7.4.1	Results	151
7.4.2	Comparison with high gain observers under sensor failure	155
7.5	Conclusions	156
8	Specific Kinetic Rates Regulation in Multi-Substrate Fermentation Processes	159
8.1	Introduction	160
8.2	Problem formulation	161
8.3	Nonlinear PI controller and second order sliding mode observer	163
8.3.1	Nonlinear PI control	164
8.3.2	Multiple rates observer	165
8.4	Simulations	166
8.5	Conclusions	169
III	Synthetic genetic circuits design	171
9	Control of protein concentrations in heterogeneous cell populations	173
9.1	Introduction	174
9.2	System description	176
9.2.1	Cell-to-cell communication and feedback controller	176
9.2.2	Mathematical model	177
9.3	Approximation of the intracellular controller	179

9.4	Operation in the linear regime	180
9.5	Control of protein mean and variance	183
9.6	Simulations	184
9.7	Conclusions	188
General discussion		189
Conclusions of the thesis		191
Bibliography		199
Appendices		217
A	Proofs	219
A.1	Global topology analysis	219
A.2	Local topology analysis	220
A.3	Minimum χ function generalized gradient	223
A.4	Proof of Theorem 9.1	224
A.5	Proof of Theorem 9.2	226
B	Algorithms and examples.	229
B.1	Individual systems dynamics	229