

Contents

1	Introduction and Problem Statement	1
1.1	Adaptation Against Uncertainties	1
1.2	Challenges of Signal Uncertainties	7
1.3	Output Regulation	17
1.3.1	Nonadaptive Output Regulation: Problem Statement and the Francis Equation	17
1.3.2	Decomposition on Tracking and Rejection	21
1.3.3	Adaptive Output Regulation: Statements of the Problems	25
1.4	Internal Model and Output Regulation: An Overview	28
1.5	Internal Model and Output Regulation: Practical Implementations	31
1.5.1	Vibration Control	31
1.5.2	Ripple Reduction in AC–DC Converters	32
1.5.3	Ripple Reduction in Permanent Magnet Synchronous Motors	34
1.5.4	Crane Vessel Control	35
	References	36
2	Exosignals: Models and Observers	43
2.1	Exosignal Models	43
2.2	Exosystem Canonical Form	49
2.3	Reference Observer	57
2.4	Disturbance Observers: Plants with Known Parameters	58
2.4.1	Disturbance Observers for LTI Plants	58
2.4.2	Disturbance Observers for Nonlinear Plants	68
2.5	Disturbance Observers: Plants with Unknown Parameters	76
2.5.1	Disturbance Observers for LTI Plants	76
2.5.2	Disturbance Observers for Nonlinear Plants	85
	References	93

3	Basic Algorithms of Adaptation	95
3.1	Parameterizations and Error Models	95
3.2	Algorithms for Static Error Model	99
3.2.1	Gradient Algorithm of Adaptation	100
3.2.2	Adaptation Algorithm with Dynamic Regressor Extension	104
3.2.3	Adaptation Algorithm with Memory Regressor Extension	107
3.3	Algorithms for Dynamic Error Model with Accessible State	114
3.3.1	Adaptive Stabilization	116
3.3.2	Nonlinear Damping	119
3.4	Algorithms for Dynamic Error Model with Accessible Output	123
3.4.1	Adaptive Output Stabilization of Strictly Passive Systems	124
3.4.2	Swapping-Based Adaptation	126
3.5	Robust Algorithms of Adaptation	130
	References	137
4	Adaptive Regulation in Systems with Known Parameters	139
4.1	LTI SISO Plants	139
4.1.1	Reference Tracking	139
4.1.2	Compensation of Matched Disturbance	154
4.1.3	Compensation of Unmatched Disturbance	157
4.1.4	Regulation in LTI SISO Plants	176
4.2	LTI MIMO Plants	181
4.2.1	Reference Tracking	182
4.2.2	Compensation of Unmatched Disturbance	192
4.2.3	Regulation in LTI MIMO Plants	195
4.3	Disturbance Compensation in Nonlinear Plants	199
4.3.1	Plant in the General Form	201
4.3.2	Plant in the Normal Canonical Form	204
4.3.3	Plant with Unmatched Disturbance and Measured State	208
4.3.4	Plant with Unmatched Disturbance and Measured Output	214
	References	220
5	Adaptive Regulation in Systems with Unknown Parameters	223
5.1	LTI SISO Plants	223
5.1.1	Reference Tracking	223
5.1.2	Compensation of Matched Disturbance	227
5.1.3	Compensation of Unmatched Disturbance	231
5.1.4	Regulation in LTI SISO Plants	242
5.2	Nonlinear Plants	244
5.2.1	Reference Tracking	245
5.2.2	Compensation of Unmatched Disturbance	251
	References	264

6 Adaptive Regulation in LTI Plants with Input Delay	267
6.1 Reference Tracking	267
6.2 Disturbance Compensation	274
6.3 Regulation	281
References	287
7 Robust Adaptive Regulation	289
7.1 Robustness of Exosignal Observers	289
7.1.1 Reference Observer	290
7.1.2 Disturbance Observers: Plants with Known Parameters	291
7.1.3 Disturbance Observers: Plants with Unknown Parameters	292
7.2 Reference Tracking	296
7.3 Disturbance Rejection	301
7.3.1 LTI SISO Plants with Known Parameters	301
7.3.2 LTI SISO Plants with Unknown Parameters	304
7.3.3 Nonlinear Plant with Unmatched Disturbance and Measured State	306
7.4 Output Regulation	308
References	310
Appendix A: Exosignals: Parameterizations and Properties	311
Appendix B: Stability, Lyapunov Functions and Robustness	321
Appendix C: Norms and Properties of Functions	331
Appendix D: Schemes of Swapping	333
Appendix E: Adaptive Backstepping	345
Index	355