

Contents

Preface	vii
1 Introduction	1
2 Preliminaries	11
2.1 Introduction.....	11
2.2 Vector Spaces	11
2.2.1 Metric space.....	13
2.2.2 Normed vector space.....	14
2.3 Best Approximation Problem in Hilbert Space.....	15
2.4 Orthogonal Functions.....	17
2.5 Vector and Matrix Analysis	24
2.5.1 Properties of matrices.....	24
2.5.2 Differential calculus of vectors and matrices	26
2.6 Various Norms	28
2.6.1 Vector norms.....	28
2.6.2 Matrix norms.....	29
2.6.3 Function norms and normed function spaces	30
2.7 Representations for Approximation	31
2.8 Lyapunov Stability Theory	35
2.8.1 Concepts of stability.....	35
2.8.2 Lyapunov stability theorem.....	37
2.9 Sliding Control.....	39
2.10 Model Reference Adaptive Control	45
2.10.1 MRAC of LTI scalar systems	45
2.10.2 MRAC of LTI systems: vector case.....	48
2.10.3 Persistent excitation	50
2.10.4 Robust adaptive control	54

2.11	General Uncertainties	57
2.11.1	MRAC of LTV systems.....	58
2.11.2	Sliding control for systems with unknown variation bounds.....	59
2.12	FAT-Based Adaptive Controller Design	61
3	Dynamic Equations for Robot Manipulators	71
3.1	Introduction	71
3.2	Rigid Robot	71
3.3	Rigid Robot Interacting with Environment	73
3.4	Electrically-Driven Rigid Robot.....	75
3.5	Electrically-Driven Rigid Robot Interacting with Environment....	76
3.6	Flexible Joint Robot.....	77
3.7	Flexible Joint Robot Interacting with Environment.....	78
3.8	Electrically-Driven Flexible Joint Robot.....	79
3.9	Electrically-Driven Flexible Joint Robot Interacting with Environment	80
4	Adaptive Control of Rigid Robots	83
4.1	Introduction	83
4.2	Review of Conventional Adaptive Control for Rigid Robots.....	85
4.3	Slotine and Li's Approach	87
4.4	The Regressor Matrix	89
4.5	FAT-Based Adaptive Controller Design	91
4.6	Consideration of Actuator Dynamics	101
4.6.1	Regressor-based adaptive control	103
4.6.2	Regressor-free adaptive control	105
5	Adaptive Impedance Control of Rigid Robots	129
5.1	Introduction	129
5.2	Impedance Control and Adaptive Impedance Control.....	130
5.3	Regressor-Based Adaptive Impedance Controller Design.....	134
5.4	FAT-Based Adaptive Impedance Controller Design.....	136
5.5	Consideration of Actuator Dynamics	146
5.5.1	Regressor-based adaptive controller	147
5.5.2	Regressor-free adaptive controller	148

6 Adaptive Control of Flexible Joint Robots	163
6.1 Introduction.....	163
6.2 Control of Known Flexible Joint Robots	164
6.3 Regressor-Based Adaptive Control of Flexible Joint Robots	167
6.4 FAT-Based Adaptive Control of Flexible Joint Robots.....	168
6.5 Consideration of Actuator Dynamics.....	181
6.5.1 Regressor-based adaptive controller design.....	184
6.5.2 Regressor-free adaptive controller design.....	186
7 Adaptive Impedance Control of Flexible Joint Robots.....	201
7.1 Introduction.....	201
7.2 Impedance Control of Known Flexible Joint Robots.....	202
7.3 Regressor-Based Adaptive Impedance Control of Flexible Joint Robots	205
7.4 Regressor-Free Adaptive Impedance Control of Flexible Joint Robots	207
7.5 Consideration of Actuator Dynamics.....	220
7.5.1 Regressor-based adaptive controller design.....	223
7.5.2 Regressor-free adaptive controller design.....	224
Appendix	241
References	247
Symbols, Definitions and Abbreviations.....	257
Index	261