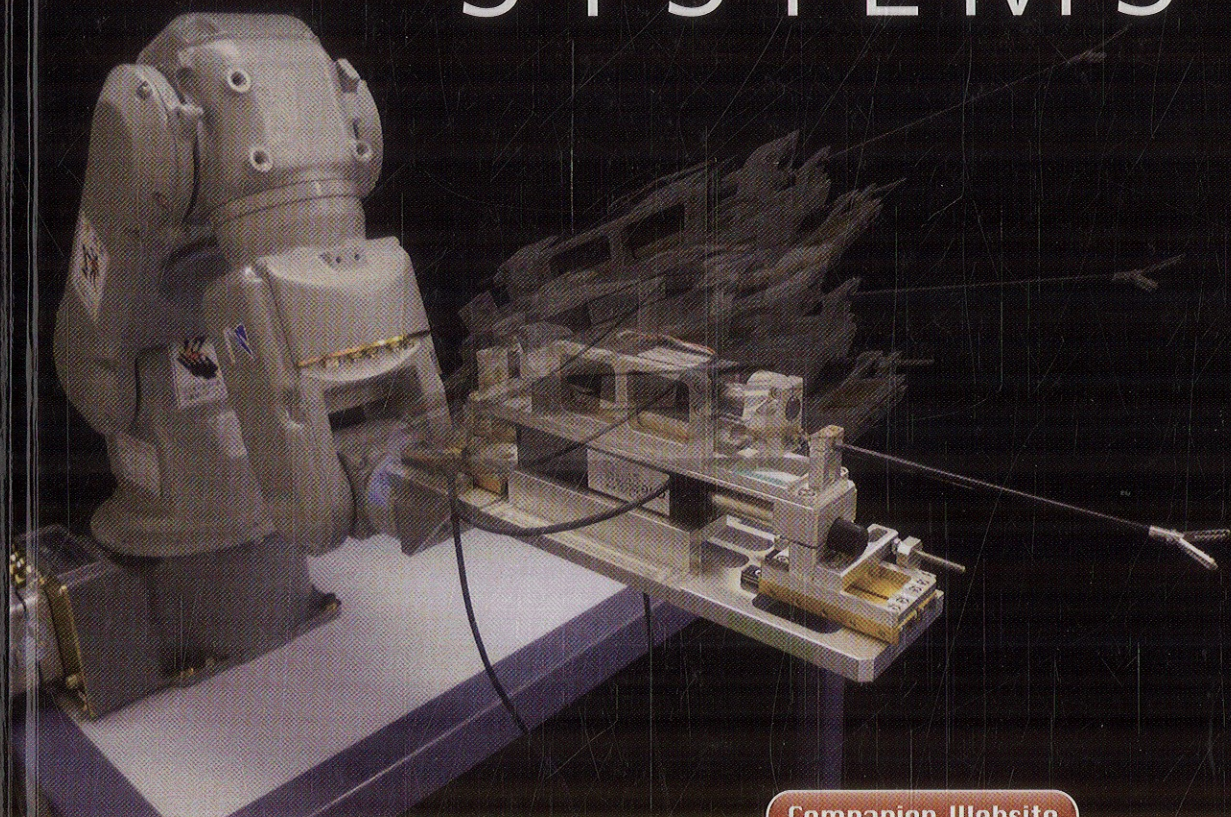


ASIF ŠABANOVIĆ | KOUHEI OHNISHI

MOTION CONTROL SYSTEMS



Companion Website



Contents

Preface	ix
About the Authors	xi
 PART ONE – BASICS OF DYNAMICS AND CONTROL	
1 Dynamics of Electromechanical Systems	3
1.1 Basic Quantities	3
1.1.1 Elements and Basic Quantities in Mechanical Systems	3
1.1.2 Elements and Basic Quantities in Electric Systems	5
1.2 Fundamental Concepts of Mechanical Systems	7
1.2.1 The Principle of Least Action	7
1.2.2 Dynamics	8
1.2.3 Nonpotential and Dissipative Forces	9
1.2.4 Equations of Motion	10
1.2.5 Properties of Equations of Motion	14
1.2.6 Operational Space Dynamics	18
1.3 Electric and Electromechanical Systems	20
1.3.1 Electrical Systems	20
1.3.2 Electromechanical Systems	21
1.3.3 Electrical Machines	24
References	27
Further Reading	27
 2 Control System Design	 29
2.1 Basic Concepts	30
2.1.1 Basic Forms in Control Systems	31
2.1.2 Basic Relations	35
2.1.3 Stability	36
2.1.4 Sensitivity Function	37
2.1.5 External Inputs	38
2.2 State Space Representation	39
2.2.1 State Feedback	40
2.2.2 Stability	44
2.2.3 Observers	45
2.2.4 Systems with Observers	48
2.2.5 Disturbance Estimation	49

2.3	Dynamic Systems with Finite Time Convergence	51
2.3.1	Equivalent Control and Equations of Motion	52
2.3.2	Existence and Stability	53
2.3.3	Design	53
2.3.4	Control in Linear Systems	55
2.3.5	Sliding Mode Based Observers	56
	References	59
	Further Reading	59

PART TWO – ISSUES IN MOTION CONTROL

3	Acceleration Control	63
3.1	Plant	63
3.2	Acceleration Control	67
3.2.1	Formulation of Control Tasks	68
3.2.2	Equivalent Acceleration and Equivalent Force	74
3.3	Enforcing Convergence and Stability	85
3.3.1	Convergence for Bounded Control Input	90
3.3.2	Systems with Finite-Time Convergence	94
3.3.3	Equations of Motion	97
3.3.4	General Structure of Acceleration Control	105
3.4	Trajectory Tracking	107
	References	114
	Further Reading	114
4	Disturbance Observers	115
4.1	Disturbance Model Based Observers	118
4.1.1	Velocity Based Disturbance Observer	119
4.1.2	Position Based Disturbance Observer	121
4.2	Closed Loop Disturbance Observers	127
4.2.1	Internal and External Forces Observers	128
4.3	Observer for Plant with Actuator	132
4.3.1	Plant with Neglected Dynamics of Current Control Loop	133
4.3.2	Plant with Dynamics in Current Control Loop	136
4.4	Estimation of Equivalent Force and Equivalent Acceleration	140
4.5	Functional Observers	144
4.6	Dynamics of Plant with Disturbance Observer	149
4.6.1	Disturbance Estimation Error	150
4.6.2	Dynamics of Plant With Disturbance Observer	151
4.7	Properties of Measurement Noise Rejection	160
4.8	Control of Compensated Plant	164
4.8.1	Application of Estimated $\hat{\tau}^{eq}$ and \hat{q}^{eq}	167
	References	172
	Further Reading	173

5	Interactions and Constraints	175
5.1	Interaction Force Control	176
5.1.1	Proportional Controller and Velocity Feedback	178
5.1.2	Environment with Losses	182
5.1.3	Lossless Environment	187
5.1.4	Control of Push Pull Force	191
5.2	Constrained Motion Control	193
5.2.1	Modification of Reference	195
5.2.2	Modification by Acting on Equivalent Acceleration	201
5.2.3	Motion Modification while Keeping Desired Force Profile	205
5.2.4	Impedance Control	209
5.2.5	Force Driven Systems	210
5.2.6	Position and Force Control in Acceleration Dimension	211
5.3	Interactions in Functionally Related Systems	215
5.3.1	Grasp Force Control	215
5.3.2	Functionally Related Systems	225
	References	232
	Further Reading	232
6	Bilateral Control Systems	233
6.1	Bilateral Control without Scaling	234
6.1.1	Bilateral Control Design	238
6.1.2	Control in Systems with Scaling in Position and Force	247
6.2	Bilateral Control Systems in Acceleration Dimension	251
6.3	Bilateral Systems with Communication Delay	256
6.3.1	Delay in Measurement Channel	257
6.3.2	Delay in Measurement and Control Channels	263
6.3.3	Closed Loop Behavior of System with Observer	267
6.3.4	Bilateral Control in Systems with Communication Delay	270
	References	274
	Further Reading	274

PART THREE – MULTIBODY SYSTEMS

7	Configuration Space Control	279
7.1	Independent Joint Control	280
7.2	Vector Control in Configuration Space	281
7.2.1	Selection of Desired Acceleration	282
7.3	Constraints in Configuration Space	290
7.3.1	Enforcement of Constraints by Part of Configuration Variables	303
7.4	Hard Constraints in Configuration Space	304
	References	311
	Further Reading	312

8	Operational Space Dynamics and Control	313
8.1	Operational Space Dynamics	314
8.1.1	Dynamics of Nonredundant Tasks	314
8.1.2	Dynamics of Redundant Tasks	315
8.2	Operational Space Control	318
8.2.1	Nonredundant Task Control	319
8.2.2	Redundant Task Control	328
	References	336
	Further Reading	336
9	Interactions in Operational Space	337
9.1	Task–Constraint Relationship	337
9.2	Force Control	341
9.3	Impedance Control	345
9.4	Hierarchy of Tasks	347
9.4.1	Constraints in Operational Space	347
9.4.2	Enforcing the Hierarchy of Tasks	352
9.4.3	Selection of Configuration Space Desired Acceleration	357
	References	358
	Further Reading	358
	Index	361