

Contents

Preface	xi
The Author	xiii
1. Introduction	1
1.1 Scope and Outline	3
1.2 Mechanics and Nonlinear Control	6
1.3 Role of Modeling in a Control Design Process	20
References	21
2. Dynamics Modeling of Constrained Systems	25
2.1 Introduction—Art of Modeling	25
2.1.1 Selection of Coordinates	26
2.1.2 Generalized Velocities and Quasi-Velocities	29
2.2 Constrained Systems	31
2.2.1 Holonomic Constraints	32
2.2.2 Nonholonomic Constraints	33
2.2.3 Programmed Constraints	35
2.3 Equations of Motion for Systems with First Order Constraints	37
2.3.1 D'Alembert Principle	38
2.3.2 Lagrange's Equations for Holonomic Systems	45
2.3.3 Lagrange's Equations for First Order Nonholonomic Systems	50
2.3.4 Maggi's Equations	52
2.3.5 Nielsen's Equations	55
2.3.6 Equations of Motion in Quasi-Coordinates	58
2.4 Equations of Motion for Systems with High Order Constraints	67
2.4.1 An Extended Concept of Constraints—Programmed Constraints	67
2.4.2 Generalized Programmed Motion Equations Specified in Generalized Coordinates	76
2.4.3 Generalized Programmed Motion Equations Specified in Quasi-Coordinates	88
Problems	94
References	94

3. Introduction to Nonlinear Control Theory	99
3.1 Stability Properties of Nonlinear Systems	99
3.1.1 State-Space Representation of Nonlinear Systems.....	99
3.1.2 Stability Theorems of the Lyapunov Direct Method	101
3.1.3 Special Formulations of Stability Theorems	103
3.2 Classification of Control Problems	111
3.2.1 Stabilization	112
3.2.2 Trajectory and Motion Tracking	115
3.2.3 Path Following.....	117
3.3 Control Properties of Nonlinear Systems.....	118
3.3.1 Classification of Constrained Control Systems	118
3.3.2 Accessibility and Controllability	122
3.3.3 Stabilizability	131
3.3.4 Differential Flatness	135
3.4 Kinematic Control Models.....	136
3.5 Dynamic Control Models	144
3.6 Feedback Linearization of Nonlinear Systems	147
3.7 Model-Based Control Design Methods.....	152
3.8 Flatness-Based Control Design Methods	155
3.8.1 Basic Notions of Equivalence and Flatness.....	155
3.8.2 Flatness in Control Applications	159
3.8.3 Flatness-Based Control Design—Examples.....	161
3.8.4 Concluding Remarks—Verifying Flatness.....	167
3.9 Other Control Design Techniques for Nonlinear Systems	167
3.9.1 Backstepping	169
3.9.2 Sliding Mode Control	173
Problems.....	175
References	176
4. Stabilization Strategies for Nonlinear Systems	183
Problems.....	189
References	189
5. Model-Based Tracking Control of Nonlinear Systems.....	191
5.1 A Unified Control-Oriented Model for Constrained Systems ...	191
5.2 Tracking Control of Holonomic Systems.....	196
5.3 Tracking Control of First Order Nonholonomic Systems	200
5.4 Tracking Control of Underactuated Systems	206
5.5 Tracking Control Algorithms Specified in Quasi-Coordinates	212
Problems.....	222
References	222

- 6. Path Following Strategies for Nonlinear Systems 225
 - 6.1 Path Following Strategies Based on Kinematic Control Models..... 226
 - 6.2 Path Following Strategies Based on Dynamic Control Models 229
 - Problems..... 231
 - References 231

- 7. Model Reference Tracking Control of High Order Nonholonomic Systems 233
 - 7.1 Model Reference Tracking Control Strategy for Programmed Motion 234
 - 7.1.1 A Reference Dynamic Model for Programmed Motion 234
 - 7.1.2 Architecture of the Model Reference Tracking Control Strategy for Programmed Motion..... 235
 - 7.1.3 A Controller Design for Programmed Motion Tracking 237
 - 7.2 Non-Adaptive Tracking Control Algorithms for Programmed Motions 240
 - 7.2.1 Programmed Motion Tracking for a Unicycle..... 240
 - 7.2.2 Programmed Motion Tracking for a Planar Manipulator 242
 - 7.2.3 Programmed Motion Tracking for a Two-Wheeled Mobile Robot..... 246
 - 7.3 Adaptive Tracking Control Algorithms for Programmed Motions 249
 - 7.3.1 Adaptive Programmed Motion Tracking for a Planar Manipulator 250
 - 7.3.2 Adaptive Programmed Motion Tracking for a Unicycle..... 254
 - 7.4 Learning Tracking Control Algorithms for Programmed Motions 258
 - 7.5 Tracking Control Algorithms for Programmed Motions Specified in Quasi-Coordinates 261
 - 7.5.1 Tracking Control of the Unicycle Model Specified in Quasi-Coordinates 262
 - 7.5.2 Tracking Control of the Planar Manipulator Model Specified in Quasi-Coordinates 262
 - 7.6 Tracking Control Algorithms for Programmed Motions with the Velocity Observer 264
 - 7.7 Other Applications of the Model Reference Tracking Control Strategy for Programmed Motion 270
 - 7.7.1 Hybrid Programmed Motion-Force Tracking..... 270

Contents

7.7.2	Application of a Kinematic Model as a Reference Model for Programmed Motions.....	277
7.7.3	Robot Formation Control.....	281
	Problems.....	290
	References	290
8.	Concluding Remarks	293
Index		297