

Contents

1	Introduction	1
1.1	Mobile Robotics	2
1.1.1	Autonomous Robots	3
1.1.2	Other Classifications of Mobile Robots	5
1.2	Vehicle-Manipulator Systems	5
1.2.1	Definition	6
1.2.2	Classifications of Vehicle-Manipulator Systems	6
1.2.3	Challenges of Implementing Vehicle-Manipulator Systems	9
1.2.4	The Importance of Robust Solutions	11
1.2.5	A Larger Perspective	12
	References	12
2	Preliminary Mathematical Concepts	15
2.1	Reference Frames	17
2.1.1	Inertial Reference Frames	17
2.1.2	Non-inertial Reference Frames	18
2.2	Coordinate Systems	19
2.2.1	Cartesian Basis	20
2.3	Euclidean and Non-Euclidean Transformations	22
2.4	Quasi-coordinates and Quasi-velocities	25
2.5	Topological Spaces and Manifolds	27
2.5.1	Coordinate Charts	31
2.5.2	Manifolds Again	35
2.6	Lie Groups	36
2.6.1	Some Important Lie Groups	38
2.6.2	Matrix Lie Groups	41
2.6.3	Local Coordinates of Matrix Lie Groups	46
2.6.4	Lie Algebra	46
2.6.5	Geometric Interpretation of Lie Group Representations	50
2.6.6	Actions on Lie Groups	57
2.7	Tangent Spaces, Vector Fields, and Integral Curves	69

2.7.1	Tangent Spaces	69
2.7.2	Vector Fields, Flows, and Integral Curves	71
2.8	The Exponential Map	73
2.8.1	The Exponential of a Matrix	74
2.8.2	Differential Equations	75
2.8.3	The Natural Path in a Matrix Group	76
2.8.4	Rigid Body Motion in Terms of Exponential Coordinates	78
2.8.5	The Exponential Map of the Most Important Lie Groups	79
2.8.6	Charts and Exponential Maps	82
2.9	Local Coordinates and Velocity Transformation Matrices	85
2.9.1	Velocity Transformation Matrices in Dynamics	85
2.9.2	The Velocity Transformation Matrix in Terms of Exponential Coordinates	86
2.10	Geometric Integrators	88
	References	89
3	Rigid Body Kinematics	91
3.1	Translational Motion in \mathbb{R}^3	91
3.1.1	Spatial Linear Velocities	93
3.2	Rotational Motion in \mathbb{R}^3	93
3.2.1	The Euler Angles	94
3.2.2	The Rotation Matrix	95
3.2.3	The Quaternion Representation	97
3.2.4	Angular Velocity and Angular Acceleration	98
3.2.5	The Relation Between Euler Angle Derivatives and Twists	100
3.3	Rigid Body Transformations	104
3.3.1	Vector Representation	104
3.3.2	Singularities in the Representation	106
3.3.3	Configuration States as Matrix Lie Groups	108
3.3.4	The Special Euclidean Group	109
3.3.5	Configuration Spaces as Subgroups of $SE(3)$	113
3.3.6	Local Coordinates	120
	References	123
4	Kinematics of Manipulators on a Fixed Base	125
4.1	Static Kinematics	126
4.1.1	Reference Frames	126
4.1.2	Homogeneous Transformations	129
4.1.3	Product of Exponentials Formula	133
4.2	The Manipulator Twists	135
4.3	Manipulator Velocities	145
4.4	Manipulator Jacobian	149
4.4.1	Body Geometric Jacobian	150
4.4.2	Spatial Geometric Jacobian	156
4.4.3	The Geometric Jacobian of the Manipulator Links	161
4.4.4	Analytical Jacobian	163

4.5	Configuration States	164
4.5.1	Local Coordinates	167
	References	167
5	Kinematics of Vehicle-Manipulator Systems	169
5.1	Configuration Space	169
5.2	Velocity Transformation Matrices	172
5.2.1	Twist and Position Variables	172
5.2.2	Link Velocities	173
5.2.3	The Geometric Jacobian	178
5.2.4	Workspace Jacobian	179
5.3	Configuration States	181
5.3.1	Local Coordinates	181
5.4	Some Simple Examples	183
	References	189
6	Rigid Body Dynamics	191
6.1	Lagrangian Mechanics	193
6.1.1	Kinetic Energy	195
6.1.2	Potential Energy	197
6.1.3	The Euler–Lagrange Equations of Motion	197
6.1.4	The Dynamic Equations in Matrix Form	199
6.2	Euler–Lagrange Equations for Rigid Body Motion	199
6.2.1	Euler–Lagrange Equations in Matrix Form	203
6.3	Full State Space Dynamics in Vector Form	205
6.4	Lagrange Equations of Motion in Quasi-coordinates	207
6.4.1	The Euler–Lagrange Equations in Matrix Form	212
6.4.2	Local Parameterization	213
6.4.3	The Most Important Configuration Spaces	218
6.4.4	Other Formulations in Quasi-coordinates	225
	References	226
7	Dynamics of Manipulators on a Fixed Base	229
7.1	Kinetic and Potential Energy in Multibody Systems	229
7.2	Lagrangian Dynamics	235
7.2.1	Robot Dynamics in Matrix Form	236
7.2.2	Operational Space Approach	238
7.3	Configuration States	240
7.4	The Euler–Lagrange Equations of Motion in Quasi-coordinates	241
7.5	Robot Dynamics in Matrix Form	243
7.6	Local Parameterization	244
	References	245
8	Dynamics of Vehicle-Manipulator Systems	247
8.1	The Dynamic Equations in Terms of Quasi-velocities	248
8.2	The Dynamic Equations in Terms of Generalized Coordinates and Quasi-velocities	252

- 8.2.1 Full State Space Dynamics in Vector Form 258
- 8.2.2 Operational Space Approach 259
- 8.3 Configuration States 260
 - 8.3.1 Local Parameterization 266
 - 8.3.2 Dynamic Structure of Vehicle-Manipulator Systems 270
 - 8.3.3 The Most Important Configuration Spaces 271
 - 8.3.4 Examples 278
- References 283
- 9 Properties of the Dynamic Equations in Matrix Form 285**
 - 9.1 Misconceptions in the Literature 286
 - 9.2 The Boundedness and Skew-Symmetric Properties in Control 288
 - 9.2.1 Properties of the Dynamics in Matrix Form 288
 - 9.2.2 Robust Control 290
 - 9.2.3 PD Control Law 292
 - 9.3 Single Rigid Bodies 292
 - 9.3.1 The Boundedness Property 293
 - 9.3.2 The Skew-Symmetric Property 294
 - 9.4 Robotic Manipulators on a Fixed Base 296
 - 9.4.1 The Boundedness Property 297
 - 9.4.2 The Skew-Symmetric Property 299
 - 9.5 Vehicle-Manipulator Systems 301
 - 9.5.1 The Boundedness Property 301
 - 9.5.2 The Skew-Symmetric Property 302
 - References 304
- 10 Underwater Robotic Systems 307**
 - 10.1 Introduction 307
 - 10.1.1 Operating Under Water 308
 - 10.1.2 Underwater Vehicle-Manipulator Systems—A Brief Historical Overview 310
 - 10.1.3 Underwater Manipulators 312
 - 10.2 Dynamics of Underwater Vehicles 313
 - 10.2.1 Full State Space Dynamics in Vector Form 319
 - 10.3 AUV-Manipulator Dynamics 320
 - 10.3.1 Operational Space Approach 321
 - 10.4 Configuration States 322
 - References 323
- 11 Spacecraft-Manipulator Systems 325**
 - 11.1 Introduction 325
 - 11.1.1 Operating in Space 326
 - 11.1.2 Space Exploration 329
 - 11.1.3 Disturbances 332
 - 11.1.4 Actuators 333
 - 11.1.5 Coordinate Frames 335

11.2	Free-Floating and Free-Flying Rigid Bodies	336
11.2.1	Spacecraft Kinematics	336
11.2.2	Spacecraft Dynamics	336
11.3	Modeling of Free-Floating and Free-Flying Robots	337
11.3.1	Kinematics of Spatial Vehicle-Manipulator Systems	337
11.3.2	Dynamics of Spatial Vehicle-Manipulator Systems	345
11.4	The Dynamically Equivalent Manipulator Approach	348
11.4.1	Mathematical Formulation	350
11.4.2	Configuration States	352
	References	353
12	Field Robots	355
12.1	Introduction	355
12.1.1	Earth-Based Systems	356
12.1.2	Space Robots	357
12.1.3	Locomotion	357
12.1.4	Mobility and Configuration Spaces	359
12.1.5	Non-holonomic Motion	360
12.2	Modeling of Wheeled Robots	362
12.2.1	Chassis Kinematics	362
12.2.2	Wheel Kinematics	366
	References	368
13	Robotic Manipulators Mounted on a Forced Non-inertial Base	369
13.1	Introduction	369
13.1.1	Seaborne Platforms	370
13.1.2	Active Heave Compensation	370
13.1.3	Land Vehicles	371
13.2	Dynamics of Manipulators on a Forced Base	373
13.3	Motion Planning and Control	375
13.3.1	Canceling the Inertial Forces	375
13.3.2	Leveraging the Inertial Forces	376
	References	377
Appendix	Implementation and Proofs	379
A.1	Computing the Partial Derivatives of the Inertia Matrix	379
A.1.1	Computing the Partial Derivatives of $Ad_{g_{ij}}$	379
A.1.2	Computing the Jacobian and Its Partial Derivatives	382
A.1.3	Implementation	382
Index	385



<http://www.springer.com/978-1-4471-5462-4>

Vehicle-Manipulator Systems

Modeling for Simulation, Analysis, and Control

From, P.J.; Gravdahl, J.T.; Pettersen, K.Y.

2014, XXIV, 388 p. 52 illus., 33 illus. in color., Hardcover

ISBN: 978-1-4471-5462-4