

Contents

Preface	ix
I Introductory Material	1
1 Introduction	3
1.1 Planning to Plan	3
1.2 Motivational Examples and Applications	5
1.3 Basic Ingredients of Planning	17
1.4 Algorithms, Planners, and Plans	19
1.5 Organization of the Book	24
2 Discrete Planning	27
2.1 Introduction to Discrete Feasible Planning	28
2.2 Searching for Feasible Plans	32
2.3 Discrete Optimal Planning	43
2.4 Using Logic to Formulate Discrete Planning	57
2.5 Logic-Based Planning Methods	63
II Motion Planning	77
3 Geometric Representations and Transformations	81
3.1 Geometric Modeling	81
3.2 Rigid-Body Transformations	92
3.3 Transforming Kinematic Chains of Bodies	100
3.4 Transforming Kinematic Trees	112
3.5 Nonrigid Transformations	120
4 The Configuration Space	127
4.1 Basic Topological Concepts	127
4.2 Defining the Configuration Space	145
4.3 Configuration Space Obstacles	155
4.4 Closed Kinematic Chains	167

5	Sampling-Based Motion Planning	185
5.1	Distance and Volume in C-Space	186
5.2	Sampling Theory	195
5.3	Collision Detection	209
5.4	Incremental Sampling and Searching	217
5.5	Rapidly Exploring Dense Trees	228
5.6	Roadmap Methods for Multiple Queries	237
6	Combinatorial Motion Planning	249
6.1	Introduction	249
6.2	Polygonal Obstacle Regions	251
6.3	Cell Decompositions	264
6.4	Computational Algebraic Geometry	280
6.5	Complexity of Motion Planning	298
7	Extensions of Basic Motion Planning	311
7.1	Time-Varying Problems	311
7.2	Multiple Robots	318
7.3	Mixing Discrete and Continuous Spaces	327
7.4	Planning for Closed Kinematic Chains	337
7.5	Folding Problems in Robotics and Biology	347
7.6	Coverage Planning	354
7.7	Optimal Motion Planning	357
8	Feedback Motion Planning	369
8.1	Motivation	369
8.2	Discrete State Spaces	371
8.3	Vector Fields and Integral Curves	381
8.4	Complete Methods for Continuous Spaces	398
8.5	Sampling-Based Methods for Continuous Spaces	412
III	Decision-Theoretic Planning	433
9	Basic Decision Theory	437
9.1	Preliminary Concepts	438
9.2	A Game Against Nature	446
9.3	Two-Player Zero-Sum Games	459
9.4	Nonzero-Sum Games	468
9.5	Decision Theory Under Scrutiny	477
10	Sequential Decision Theory	495
10.1	Introducing Sequential Games Against Nature	496
10.2	Algorithms for Computing Feedback Plans	508

10.3	Infinite-Horizon Problems	522
10.4	Reinforcement Learning	527
10.5	Sequential Game Theory	536
10.6	Continuous State Spaces	551
11	Sensors and Information Spaces	559
11.1	Discrete State Spaces	561
11.2	Derived Information Spaces	571
11.3	Examples for Discrete State Spaces	581
11.4	Continuous State Spaces	589
11.5	Examples for Continuous State Spaces	598
11.6	Computing Probabilistic Information States	614
11.7	Information Spaces in Game Theory	619
12	Planning Under Sensing Uncertainty	633
12.1	General Methods	634
12.2	Localization	640
12.3	Environment Uncertainty and Mapping	655
12.4	Visibility-Based Pursuit-Evasion	684
12.5	Manipulation Planning with Sensing Uncertainty	691
IV	Planning Under Differential Constraints	711
13	Differential Models	715
13.1	Velocity Constraints on the Configuration Space	716
13.2	Phase Space Representation of Dynamical Systems	735
13.3	Basic Newton-Euler Mechanics	745
13.4	Advanced Mechanics Concepts	762
13.5	Multiple Decision Makers	780
14	Sampling-Based Planning Under Differential Constraints	787
14.1	Introduction	788
14.2	Reachability and Completeness	798
14.3	Sampling-Based Motion Planning Revisited	810
14.4	Incremental Sampling and Searching Methods	820
14.5	Feedback Planning Under Differential Constraints	837
14.6	Decoupled Planning Approaches	841
14.7	Gradient-Based Trajectory Optimization	855
15	System Theory and Analytical Techniques	861
15.1	Basic System Properties	862
15.2	Continuous-Time Dynamic Programming	870
15.3	Optimal Paths for Some Wheeled Vehicles	880

15.4 Nonholonomic System Theory	888
15.5 Steering Methods for Nonholonomic Systems	910