

Contents

Preface	ix
Acknowledgments	xi
List of figures	xiii
List of tables	xvii
List of abbreviations and acronyms	xix
1 Introduction	1
1.1 Why rovers?	3
1.2 Space project management	15
1.2.1 Project planning	18
1.2.2 Work breakdown structure	21
1.2.3 Project schedule	23
1.2.4 Project budget	24
1.2.5 Development plan	27
1.2.6 Personnel management	28
2 Planetary environments	37
2.1 The Moon	40
2.2 Mars	49
3 Survey of past rover missions	59
3.1 Lunokhod	59
3.2 Lunar roving vehicle (LRV).	61
3.3 Mars Pathfinder (MPF) Sojourner	61
3.4 Mars Exploration Rovers	63
3.5 Mars Science Laboratory	68

4	Rover mobility and locomotion	71
4.1	Wheeled vehicles	73
4.2	Articulated chassis	83
4.3	Tracked vehicles	88
4.4	Locomotion metrics	94
4.5	Terrain roughness and vehicle suspension	99
4.6	Rover mean free path	102
4.7	Vehicle–soil interaction—Bekker theory	106
4.8	Vehicle–soil interaction—the Russian approach	130
5	Rover sensorimotor control systems	133
5.1	Drive motors	133
5.2	Motor controllers	143
5.3	Locomotion control	154
5.4	Rover locomotion sensors	160
5.5	Sun sensing	166
5.6	Laser rangefinding	171
5.7	Automated traction control	174
5.8	Sensor fusion	185
6	Rover vision—fundamentals	199
6.1	General considerations for rover camera systems	199
6.2	Example camera systems	204
6.3	Vision-processing requirements	211
6.4	Camera calibration	216
6.5	Vision processing	220
6.6	Terrain imaging	250
6.7	Stereovision	254
7	Rover vision—advanced capabilities	263
7.1	Visual odometry	263
7.2	Optic flow–based navigation	269
7.3	Active vision	285
8	Autonomous navigation—behaviors and architectures	301
8.1	Telerobotics	302
8.2	Rover surface operations	312
8.3	Behavior-based autonomy	314
8.4	Intelligent rover architectures	322

9	Autonomous navigation—self-localization and mapping (SLAM)	331
9.1	Digital elevation/terrain model (DEM/DTM)	332
9.2	MER rover navigation	337
9.3	CNES/LAAS autonomous navigation system	340
9.4	Kalman filter–based SLAM	345
9.5	Unscented filter–based SLAM	357
9.6	SLAM by Bayesian estimation	360
9.7	FastSLAM	367
10	Rover path planning	375
10.1	Path planning by search algorithm	375
10.2	Path planning by potential field	383
10.3	Path planning using simulated annealing	399
10.4	Path planning using motor schemas	401
10.5	Exploration by multirover teams	406
11	Robotic sample acquisition	419
11.1	Sample acquisition by robotic manipulator	421
11.2	Sample acquisition by corer/grinder	432
11.3	Sample acquisition by subsurface drill	435
11.4	Sample acquisition by mole	452
11.5	Drill performance modeling	457
11.6	Sample handling, processing, and distribution (SHPD) devices	465
12	Onboard autonomous science	471
12.1	Visual target analysis	473
12.2	Classification by Bayesian networks	485
12.3	Saliency as a measure of interest	497
12.4	Expert system knowledge	500
12.5	Robotic field trials of autonomous science	502
12.6	Gas emission source localization	504
13	Case study: Robotic exploration of Europa	513
13.1	European cryobot	515
13.2	European hydrobot	519
13.3	Submersible dynamics	528
13.4	Planetary oceans galore	535
13.5	Subsurface ocean terrestrial analogs	536
14	Future rover concepts	541
	Appendix Brief review of Bayesian and associated methods	563
	References	581
	Index	663