

Contents

Abbreviations and acronyms	xxi
1 Introduction	1
1.1 Goals and structure of the book	1
1.2 Definitions and terms	1
1.3 Quality parameters	4
1.4 Applications and phases of navigation	5
1.5 User requirements	6
1.6 Miscellaneous	7
2 Historical review	9
2.1 Origins of navigation	9
2.2 Hellenistic period and Roman Empire	10
2.3 Middle ages	11
2.4 Seventeenth and eighteenth century	12
2.5 Nineteenth and twentieth century	13
3 Mathematical fundamentals	19
3.1 Reference frames	19
3.1.1 Definitions	19
3.1.2 Transformations	23
3.1.3 Differential relations	29
3.2 Principles of position determination	31
3.2.1 Dead reckoning	31
3.2.2 Position fixing	32
3.3 Principles of velocity determination	39
3.3.1 Velocity vector	39
3.3.2 Course angle	39
3.4 Principles of attitude determination	43
3.4.1 Rigorous solution strategy	43
3.4.2 Least squares approach	45
3.5 Accuracy measures	46
3.5.1 Definitions	46
3.5.2 Accuracy equivalences	49
3.6 Least squares estimation	49
3.6.1 Least squares adjustment by parameters	49

3.6.2	Recursive least squares adjustment	50
3.6.3	Discrete Kalman filtering	52
3.7	Principles of routing and guidance	55
3.7.1	Graph theory	55
3.7.2	Combinatorial optimization	56
4	Physical fundamentals	59
4.1	Fundamentals of electromagnetic waves	59
4.1.1	Definition of electromagnetic waves	59
4.1.2	Doppler frequency shift	62
4.1.3	The electromagnetic spectrum	62
4.2	Electromagnetic wave propagation	65
4.2.1	Terminology	65
4.2.2	Atmospheric structure	66
4.2.3	Phase and group velocity	70
4.2.4	Line-of-sight, ground, and sky waves	72
4.3	Observables from electromagnetic waves	75
4.3.1	Ranges and pseudoranges	75
4.3.2	Range rates and velocities	76
4.3.3	Directions	76
5	Maps	77
5.1	Introduction	77
5.2	Types of maps	78
5.3	Map projections	80
5.4	Digital maps	83
5.4.1	Definitions	83
5.4.2	Modeling and graph theory	84
5.4.3	Navigable maps and requirements	90
5.4.4	Standardization and products	93
6	Terrestrial navigation	99
6.1	Introduction	99
6.1.1	Definitions	99
6.1.2	Units	100
6.1.3	Terms	101
6.2	Instruments and observables	105
6.2.1	Ranges	105
6.2.2	Heights and depths	108
6.2.3	Velocities	109
6.2.4	Directions	111

6.2.5	Time	113
6.3	Position determination	115
6.3.1	Techniques	115
6.3.2	Nonsimultaneous observations	115
6.4	Drift	116
6.4.1	Drift determination	117
6.4.2	Drift correction	118
7	Celestial navigation	121
7.1	Introduction	121
7.2	Astronomical basics	122
7.2.1	Coordinate systems	122
7.2.2	Time systems	127
7.3	Celestial fix by spherical resection	129
7.3.1	Observation of altitudes	130
7.3.2	Mathematical model	132
7.4	Star tracker	135
7.4.1	Star sensor	135
7.4.2	Mathematical model	136
7.4.3	Reduction of star coordinates	137
7.5	Internet sources on celestial navigation	137
8	Terrestrial radio navigation	139
8.1	Introduction	139
8.2	Point source systems	139
8.2.1	Direction finders	139
8.2.2	Nondirectional beacon	141
8.2.3	Marker beacon	141
8.2.4	VHF omnidirectional range	142
8.2.5	Doppler VOR	143
8.2.6	Distance measuring equipment	143
8.2.7	Tactical air navigation	144
8.3	Area-based systems	145
8.3.1	Phased-out systems	146
8.3.2	Loran-C	147
8.3.3	Datatrak	156
8.3.4	Digital television networks	158
8.3.5	Cellular communication networks	159
8.4	Aircraft landing systems	163
8.4.1	Instrument landing system	163
8.4.2	Microwave landing system	166

9	Satellite-based navigation	169
9.1	Introduction	169
9.2	Early systems	169
9.2.1	Transit	169
9.2.2	Tsikada	172
9.3	GPS	172
9.3.1	Basic concept	172
9.3.2	System architecture	173
9.3.3	Satellite signal and observables	176
9.3.4	System capabilities and accuracies	178
9.3.5	Modernization concept	181
9.4	GLONASS	183
9.4.1	System architecture	183
9.4.2	Comparison of GPS and GLONASS	184
9.5	Galileo	185
9.5.1	Basic concept	185
9.5.2	System architecture	186
9.5.3	Satellite signal and observables	187
9.5.4	System services	188
9.6	Other satellite-based navigation systems	189
10	Augmentation systems	191
10.1	Introduction	191
10.2	Differential GNSS	193
10.2.1	Principle	193
10.2.2	Mathematical models	194
10.2.3	Systems and concepts	199
10.2.4	Multiple-reference-station concept	201
10.2.5	Data transfer	202
10.3	Integrity monitoring	206
10.3.1	Integrity-monitoring services	208
10.3.2	Receiver autonomous integrity monitoring	208
10.4	Examples of augmentation systems	209
10.4.1	Ground-based systems	209
10.4.2	Space-based systems	212
11	Inertial navigation	215
11.1	Introduction	215
11.2	Sensors	218
11.2.1	Accelerometers	218
11.2.2	Gyroscopes	221

11.3	Navigation equations	227
11.3.1	Platform types	227
11.3.2	Inertial frame	229
11.3.3	Local-level frame	230
11.4	Platform alignment	236
11.4.1	Initial alignment	236
11.4.2	Error control	238
11.5	Navigation performance	238
11.5.1	Simplified error analysis	238
11.5.2	Influence of sensor errors	243
11.5.3	Total system performance	245
12	Image-based navigation	247
12.1	Introduction	247
12.1.1	Definitions	247
12.1.2	Navigation techniques	248
12.1.3	Specific reference frames	248
12.1.4	Sensors	251
12.2	Impacts on image-based navigation	253
12.2.1	Photogrammetry	253
12.2.2	Digital image processing	259
12.2.3	Computer vision	263
12.3	Image sequence analysis	264
12.3.1	Analysis criteria	265
12.3.2	Processing strategy	266
12.3.3	Image correspondence techniques	269
12.4	Image-based navigation techniques	272
12.4.1	Self-positioning	272
12.4.2	Remote positioning	274
12.4.3	Exemplary realizations	275
13	Integrated navigation	277
13.1	Introduction	277
13.2	Advanced Kalman filtering	277
13.3	Principles of sensor fusion	281
13.3.1	Motivation and classification	281
13.3.2	Filter design	282
13.4	Typical multisensor systems	284
13.4.1	GNSS and dead reckoning	284
13.4.2	GNSS and INS	288
13.4.3	GNSS and Loran-C	291

13.4.4	GPS, GLONASS, and Galileo	294
13.4.5	Map aiding	295
14	Routing and guidance	299
14.1	Introduction	299
14.2	Route planning	299
14.2.1	Fundamental approach	299
14.2.2	Path algorithm realization	312
14.2.3	Complex applications	321
14.3	Route guidance	329
14.3.1	Map matching	329
14.3.2	Guidance – the whole concept	333
15	Vehicle and traffic management	337
15.1	Introduction	337
15.1.1	Development of ITS	338
15.1.2	Specific aspects	341
15.2	Land-based traffic management	342
15.2.1	In-vehicle navigation systems	343
15.2.2	Advisory routing systems	345
15.2.3	Fleet management systems	348
15.2.4	Desktop routing systems	350
15.3	Maritime traffic management	351
15.3.1	Electronic chart display and information system	352
15.3.2	Vessel traffic services	354
15.4	Air traffic management	355
15.4.1	Flight management system	356
15.4.2	Air traffic control	357
15.4.3	Air traffic services	358
16	Application examples	361
16.1	Conventional applications	361
16.1.1	Land navigation	361
16.1.2	Marine navigation	362
16.1.3	Aeronautic navigation	366
16.1.4	Space navigation	373
16.2	Specific applications	375
16.2.1	Pedestrian navigation	375
16.2.2	Indoor navigation	377
16.2.3	Mobile mapping	379
16.2.4	Location-based services	381

16.2.5	Mobile robotics	384
16.3	Other applications	386
16.3.1	Geodesy	386
16.3.2	Timing	390
16.3.3	Miscellaneous applications	390
17	Critical outlook	393
	References	397
	Index	409