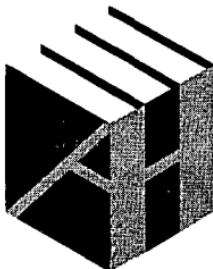


GNSS for Vehicle Control

**David M. Bevly
Stewart Cobb**



**ARTECH
HOUSE**

BOSTON | LONDON
artechhouse.com

Fachbereich 13
(TU Darmstadt)



62516380

Contents

Preface	xiii
Acknowledgments	xvii
<hr/>	<hr/>
1 GNSS and Other Navigation Sensors	1
1.1 Global Navigation Satellite System (GNSS)	1
1.1.1 Description of a Typical GNSS	2
1.1.2 Simple (Pseudorange) GNSS Navigation	3
1.1.3 Differential GNSS Navigation	6
1.1.4 Precise (RTK) GNSS Navigation	8
1.1.5 Current and Future GNSS Constellations	11
1.2 Pseudolites	14
1.2.1 Pseudolite Basics	14
1.2.2 Pseudolite/GNSS Navigation	14
1.2.3 Differential Pseudolite/GNSS Navigation	15
1.2.4 Pseudolite Self-Synchronization	16
1.2.5 Stand-Alone Pseudolite Navigation	16
1.2.6 Conflicts with GNSS Frequencies	17

1.3	Inertial Navigation Systems (INS)	18
1.3.1	Linear Inertial Instruments: Accelerometers	18
1.3.2	Angular Inertial Instruments: Gyroscopes	20
1.3.3	Ideal Inertial Navigation	21
1.3.4	Sensing Earth Effects	23
1.3.5	Inertial Instrument Errors	25
1.3.6	Inertial Error Propagation	30
1.4	Odometer Technology	31
1.4.1	Quantization	32
1.4.2	Wheel Slip	32
1.4.3	Wheel Radius Error	33
1.5	GNSS/Inertial Integration	34
	References	35
2	Vision Aided Navigation Systems	39
2.1	Lane Positioning Methods	40
2.1.1	Lidar-Based Positioning	40
2.1.2	Camera-Based Positioning	42
2.2	Coordinate Frame Rotation and Translation	43
2.2.1	Two-Dimensional Rotations	44
2.2.2	Three-Dimensional Rotations	45
2.2.3	Coordinate Frame Translation	46
2.2.4	Global Coordinate Frame Rotations	47
2.3	Waypoint-Based Maps	48
2.4	Aiding Position, Speed, and Heading Navigation Filter with Vision Measurements	49
2.4.1	Two-Dimensional Map Construction	50
2.4.2	Measurement Structure	51
2.4.3	Checking Waypoint Map Position	51
2.4.4	Results	52

2.5	Aiding Closely Coupled Navigation Filter with Vision Measurements	52
2.5.1	Three-Dimensional Map Construction	54
2.5.2	Measurement Structure	56
2.5.3	Checking Waypoint Map Position	58
2.5.4	Results	58
	References	59
3	<u>Vehicle Modeling</u>	61
3.1	Introduction	61
3.2	SAE Vehicle Coordinates	61
3.3	Bicycle Model	63
3.3.1	Basics	63
3.3.2	Understeer Gradient	70
3.3.3	Four-Wheel Bicycle Model	71
3.4	Tires	74
3.4.1	Basics	74
3.4.2	Contact Patch and Slip	74
3.4.3	Tire Models	76
3.5	Roll Model	79
3.5.1	Free Body Diagram	79
3.5.2	Equation of Motion	80
3.5.3	State Space Representation	80
3.6	Additional Models Used in this Work	80
3.6.1	Two-Wheeled Vehicle	81
3.6.2	Trailer Model	82
3.7	Vehicle Model Validation	84
	References	88

4	<u>Navigation Systems</u>	91
4.1	Introduction	91
4.2	Kalman Filter	92
4.3	GPS/INS Integration Architectures	93
4.3.1	Loose Coupling	93
4.3.2	Close Coupling	94
4.4	Speed Estimation	95
4.4.1	Accelerometer and GPS	96
4.4.2	Accelerometer, GPS, and Wheel Speed	102
4.5	Heading Estimation	107
4.6	Position, Speed, and Heading Estimation	111
4.6.1	Coordinate Conversion	112
4.6.2	Accelerometer, Yaw Rate Gyroscope, GPS, and Wheel Speed	113
4.7	Navigation in the Presence of Sideslip	120
4.7.1	Generation of Sideslip	120
4.7.2	Sideslip Compensation with a Dual Antenna GPS Receiver	122
4.8	Closely Coupled Integration	130
	References	143
5	<u>Vehicle Dynamic Estimation Using GPS</u>	145
5.1	Introduction	145
5.2	Sideslip Calculation	146
5.3	Vehicle Estimation	147

5.4	Experimental Setup	148
5.4.1	Test Scenarios	148
5.5	Kinematic Estimator (Single GPS Antenna)	149
5.6	Kinematic Kalman Filter (Dual Antenna)	151
5.7	Tire Parameter Identification	154
5.8	Model-Based Kalman Filter	160
5.8.1	Linear Tire Model	161
5.8.2	Nonlinear Tire Model	164
5.8.3	Estimator Accuracies	170
5.9	Conclusions	171
	Acknowledgments	172
	References	172
6	GNSS Control of Ground Vehicles	175
6.1	Introduction	175
6.2	Vehicle Model	175
6.3	Speed Controller	179
6.4	Vehicle Steering Control	181
6.4.1	Classical Steer Angle Controller	181
6.4.2	Classical Yaw Rate Controller	182
6.5	Waypoint Control	185
6.5.1	Heading Model	185
6.5.2	Heading Error Calculations	186
6.5.3	Heading Control	187
6.5.4	Simulation Results	190

6.6	Lateral Control	192
6.6.1	Error Calculation	193
6.6.2	Lateral Position Model	198
6.6.3	Lateral Position Control	200
6.6.4	Simulation Results	203
6.7	Implement/Trailer Control	203
6.7.1	Trailer Model	204
6.7.2	Error Calculation	206
6.7.3	Trailer Control	208
6.7.4	Simulation Results	210
	References	212
7	Pseudolites for Vehicle Navigation	215
7.1	Pseudolite Applications	215
7.1.1	Open-Pit Mining	216
7.1.2	Construction Sites	218
7.1.3	Urban Navigation	218
7.1.4	Indoor Applications	219
7.2	Pseudolite Systems	221
7.2.1	IntegriNautics IN400	221
7.2.2	Novariant Terralite XPS System	223
7.2.3	Locata LocataLites	225
	References	226
Appendix	Estimation Methods	229
A.1	Introduction	229
A.2	System Model	229
A.3	Discretization	231

A.4	Least Squares	233
A.5	Weighted Least Squares	236
A.6	Recursive Weighted Least Squares	243
A.7	Kalman Filter	246
A.8	Extended Kalman Filter	249
A.9	Initialization	252
	References	252
About the Authors		253
Index		257