

Contents

1	Introduction	1
1.1	Motivation	1
1.2	Aim of the Thesis	4
1.3	Structure	7
2	Preliminaries	8
2.1	Vehicle Dynamics and Relative Kinematics	8
2.1.1	Vehicle Modeling	8
2.1.2	Tire Modeling	11
2.1.3	Relative Kinematics of Vehicle and Evasion Path	19
2.2	Experimental Setup	20
2.2.1	Sensors	22
2.2.2	Actuators	25
2.2.3	Physical Interconnection	29
2.3	GNSS-based Collision Avoidance	30
2.4	Low-cost GNSS-based Autonomous Vehicle Guidance	33
3	Navigation	36
3.1	Motivation and Related Work	36
3.2	Requirements on Navigation Solution	39
3.3	Basic Definitions and Integration Scheme	42
3.3.1	Reference Frames	42
3.3.2	Euler Angles and Quaternions	44
3.3.3	Loosely Coupled GNSS/INS Integration	45
3.4	INS Mechanization	47
3.4.1	Sensor Error Model	48
3.4.2	Attitude	49
3.4.3	Velocity	50
3.4.4	Position	50
3.4.5	A Priori Navigation Solution	51
3.5	Loosely Coupled Error Estimation	51
3.5.1	Estimator Design	51

3.5.2	Time Delayed Measurements	55
3.5.3	Aided Heading Estimation	59
3.6	Error Correction and Navigation Solution	63
3.6.1	Error Correction	63
3.6.2	Resulting Navigation Solution	64
3.7	Further Extensions for Autonomous Vehicle Guidance	64
3.7.1	Transformation to Maneuver Reference Frame	65
3.7.2	Filter Modifications	67
3.8	Experimental Results	70
3.8.1	Test Scenario and Filter Parameterization	70
3.8.2	Position	71
3.8.3	Velocity	73
3.8.4	Attitude	74
3.8.5	Assessment of Navigation Performance	75
4	Vehicle State Estimation	76
4.1	Motivation and Related Work	76
4.2	Transformation of Navigation Outputs	79
4.3	Modeling	80
4.3.1	Vehicle Model	80
4.3.2	Tire Model	81
4.3.3	Resulting Vehicle Dynamics Model	83
4.4	Model Validation	84
4.5	Estimator Design	86
4.6	Observability Analysis	89
4.6.1	Local Observability	89
4.6.2	Assessment of Local Observability	91
4.7	Experimental Results	94
4.7.1	Test Scenarios and Filter Parameterization	94
4.7.2	Nominal Estimator Results	95
4.7.3	Adaptive Estimator Results	99
5	Optimal Vehicle Dynamics Control	103
5.1	Motivation and Related Work	103
5.2	Lateral Vehicle Guidance	107
5.2.1	Problem Statement	107
5.2.2	Modeling	108
5.2.3	Model Validation	111

5.2.4	Predictive Control Problem	114
5.3	Combined Longitudinal and Lateral Vehicle Guidance	117
5.3.1	Problem Statement	117
5.3.2	Modeling	118
5.3.3	Model Validation	123
5.3.4	Predictive Control Problem	126
5.4	Constraints on Tire Sideslip Angles	129
5.5	Static Path/Trajectory Planning	131
5.5.1	Basic Principles	131
5.5.2	Path Displacement and Relative Orientation	132
5.5.3	Prediction of Path Curvature	134
5.6	Disturbance Estimation	136
5.6.1	Estimation Problem	136
5.6.2	Modeling	137
5.6.3	Estimator Design	138
5.6.4	Observability Analysis	139
6	Experimental Control Results	142
6.1	Scenarios and Controller Parameterization	142
6.2	Lateral Vehicle Guidance	144
6.2.1	Nominal Controller	145
6.2.2	Adaptive Controller	151
6.3	Combined Longitudinal and Lateral Vehicle Guidance	154
6.3.1	Velocity Reference Generation	154
6.3.2	Low-cost GNSS-based Control Results	156
6.3.3	OxTS-based Control Results	159
6.4	Assessment of Control Results	162
7	Conclusion and Outlook	164
7.1	Conclusion	164
7.2	Outlook	166
A	Nomenclature	168
A.1	Symbols and Notations	168
A.2	Acronyms	172
B	Parameters of Experimental Setup	174

C Appendix to Navigation	176
C.1 Direction Cosine Matrix	176
C.2 Quaternions	177
C.2.1 Quaternion Multiplication	177
C.2.2 Quaternion to Direction Cosine Matrix	177
C.3 Skew Symmetric Matrix	178
C.4 Model Equations	178
C.5 Filter Parameterization	181
D Appendix to Vehicle State Estimation	183
D.1 Filter Parameterization	183
E Appendix to Optimal Vehicle Dynamics Control	185
E.1 Sideslip Angle Limits for Steering-only Controller	185
E.2 Disturbance Estimator Parameterization	187
Personal Publications	188
Bibliography	189