Table of Contents

Preface xiii

Introduction xvii

I.1. Needs of ADAS systems xvii
I.2. Limitation of available ADAS systems xix
I.3. This book versus existing studies xix
I.4. Laboratory vehicle xx
I.5. Outline xxi

Chapter 1. Modeling of Tire and Vehicle Dynamics 1

1.1. Introduction 1
1.2. Tire dynamics 2
1.2.1. Tire forces and moments 2
1.2.1.1. Vertical/normal forces 2
1.2.1.2. Longitudinal forces and longitudinal slip ratio 3
1.2.1.3. Lateral forces and sideslip angle 4
1.2.1.4. Aligning moment 5
1.2.1.5. Coupling effects between longitudinal and lateral tire forces 6
1.2.2. Tire–road friction coefficient 7
1.2.2.1. Normalized longitudinal traction force 9
1.2.2.2. Normalized lateral traction force 9
1.2.3. Quasi-static tire model 10
1.2.3.1. Pacejka's magic tire model 11
1.2.3.2. Dugoff's tire model 17
1.2.3.3. Linear model 18
1.2.4. Transient tire model 18
1.3. Wheel rotational dynamics 19

1.3.1. Static tire radius 20
1.3.2. Effective tire radius 20
1.4. Vehicle body dynamics 21
1.4.1. Vehicle's vertical dynamics 22
1.4.1.1. Suspension functions 23
1.4.1.2. Quarter-car vehicle model 23
1.4.2. Vehicle planar dynamics 25
1.4.2.1. Four-wheel vehicle model 25
1.4.2.2. Wheel-ground vertical forces calculation 27
1.4.2.3. Bicycle model 30
1.4.3. Roll dynamics and lateral load transfer evaluation 31
1.5. Summary 34

Chapter 2. Estimation Methods Based on Kalman Filtering 37

2.1. Introduction 37
2.2. State-space representation and system observability 38
2.2.1. Linear system 39
2.2.2. Nonlinear system 39
2.3. Estimation method: why stochastic models? 40
2.3.1. Closed-loop observer 41
2.3.2. Choice of the observer type 42
2.4. The linear Kalman filter 43
2.5. Extension to the nonlinear case 44
2.6. The unscented Kalman filter 46
2.6.1. Unscented transformation 46
2.6.2. UKF algorithm 48
2.7. Illustration of a linear Kalman filter application: road profile estimation 50
2.7.1. Motivation 50
2.7.2. Observer design 51
2.7.3. Experimental results: observer evaluation 53
2.7.3.1. Comparison with LPA signal 53
2.7.3.2. Comparison with GMP signal 56
2.8. Summary 59

Chapter 3. Estimation of the Vertical Tire Forces 61

3.1. Introduction 61
3.1.1. Related works 62
3.2. Algorithm description 62
3.3. Techniques for lateral load transfer calculation in an open-loop scheme 64

3.3.1. Lateral acceleration calculation 65
3.3.2. Roll angle calculation 65
3.3.3. Limitation of the open-loop model 66
3.4. Observer design for vertical forces estimation 67
3.5. Vertical forces estimation 69
3.5.1. Observer O_{F_zE} design 70
3.5.2. Observer O_{F_zL} formulation 72
3.6. Analysis concerning the two-part estimation strategy 73
3.7. Models observability analysis 74
3.8. Determining the vehicle's mass 74
3.8.1. Experimental validation of the vehicle's weight identification method 75
3.9. Detection of rollover avoidance: LTR evaluation 76
3.10. Experimental validation 78
3.10.1. Regulation of observers 80
3.10.2. Evaluation of observers 81
3.10.3. Road experimental results 82
3.10.3.1. Starting-slalom-braking test 82
3.10.3.2. Circle-braking test 86
3.10.3.3. Turn test 87
3.10.3.4. Concluding remarks 93
3.10.4. Comparison between linear and nonlinear observers: O_{F_zL} versus O_{F_zE} 93
3.10.5. Observability results 94
3.10.6. LTR evaluation 94
3.10.7. Road geometry effects 97
3.11. Summary 99

Chapter 4. Estimation of the Lateral Tire Forces 101

4.1. Introduction 101
4.2. Background on lateral force parameters calculation 102
4.2.1. Lateral force parameters evaluation 103
4.2.1.1. Sideslip angle estimation 104
4.2.1.2. Tire–road friction estimation 105
4.2.1.3. Cornering stiffness estimation 106
4.2.1.4. Effect of camber angle 106
4.3. Lateral force reconstruction in an open-loop scheme 107
4.3.1. Test at low lateral acceleration level 108
4.3.2. Test at high lateral acceleration level 112
4.4. Techniques for lateral tire force evaluation 112
4.5. Estimation process for sideslip angle and individual lateral tire force estimation 115

4.5.1. Estimation algorithm 116
4.5.2. Vehicle model 117
4.5.3. Dynamic tire model representation 118
4.5.4. Reference lateral tire force model 119
4.5.5. Further consideration for the cornering stiffness C_α 120
4.5.6. Lateral force observers: state-space representation 121
4.5.7. Observability analysis 124
4.5.8. Estimation methodologies 124
4.5.9. Sensitivity analysis of the sideslip angle estimation 125
4.6. Experimental validation 125
4.7. Pavement experimental results 128
4.7.1. Left–right bend combination test 128
4.7.2. Single left bend test 132
4.7.3. Slalom test 137
4.7.4. Circle test 141
4.7.5. Longitudinal forces estimation 143
4.7.6. Concluding remarks on experimental results 152
4.7.7. O_{F_yE} versus O_{F_yU} 153
4.7.8. Tuning of observers 153
4.8. Analysis and observations 154
4.8.1. Robustness with respect to road friction variation 156
4.9. Summary 158

Chapter 5. Embedded Real-Time System for Vehicle State Estimation: Experimental Results 159

5.1. Introduction 159
5.2. Laboratory vehicle 159
5.2.1. Embedded sensors 160
5.2.2. Software modules 164
5.2.3. DLL configuration 164
5.3. Estimation process: VSO system 165
5.4. Test tracks 167
5.5. Test results 168
5.5.1. Bourbriac test 169
5.5.2. Callac test 179
5.5.3. Rostrenen test 185
5.5.4. Concluding remarks 199
5.6. Summary 200

APPENDICES 201

Appendix 1 203

Appendix 2 207

Appendix 3 209

Appendix 4 217

Appendix 5 221

Appendix 6 225

Bibliography 227

Index 237