

INTELLIGENT

TRANSPORTATION

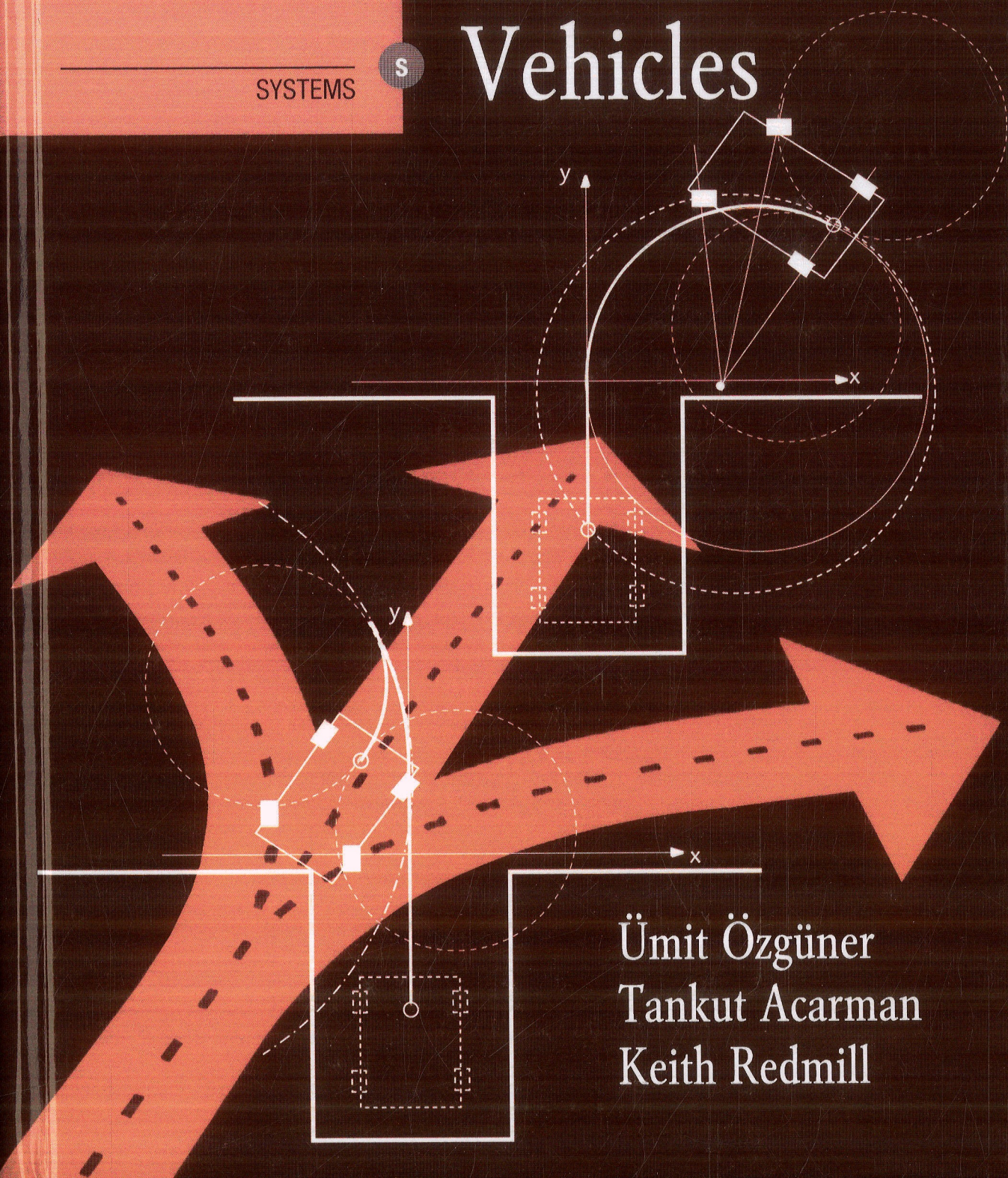
SYSTEMS

I

T

S

Autonomous Ground Vehicles



Ümit Özgüner
Tankut Acarman
Keith Redmill

Contents

Preface	ix
---------	----

CHAPTER 1

Introduction	1
1.1 Background in Autonomy in Cars	1
1.2 Components of Autonomy	2
1.2.1 Sensors	2
1.2.2 Actuators	2
1.2.3 Communication	3
1.2.4 Intelligence	3
1.3 Notes on Historical Development	3
1.3.1 Research and Experiments on Autonomous Vehicles	3
1.3.2 Autonomous Driving Demonstrations	5
1.3.3 Recent Appearances in the Market	8
1.4 Contents of This Book	10
References	11

CHAPTER 2

The Role of Control in Autonomous Systems	13
2.1 Feedback	13
2.1.1 Speed Control Using Point Mass and Force Input	13
2.1.2 Stopping	15
2.1.3 Swerving	17
2.2 A First Look at Autonomous Control	18
2.2.1 Car Following and Advanced Cruise Control	18
2.2.2 Steering Control Using Point Mass Model: Open-Loop Commands	22
2.2.3 Steering Control Using Point Mass Model: Closed-Loop Commands	28
2.2.4 Polynomial Tracking	32
2.2.5 Continuous and Smooth Trajectory Establishment	33
2.2.6 The Need for Command Sequencing	34
References	35

CHAPTER 3

System Architecture and Hybrid System Modeling	37
3.1 System Architecture	37
3.1.1 Architectures Within Autonomous Vehicles	37
3.1.2 Task Hierarchies for Autonomous Vehicles	37
3.2 Hybrid System Formulation	43
3.2.1 Discrete Event Systems, Finite State Machines, and Hybrid Systems	43
3.2.2 Another Look at ACC	44
3.2.3 Application to Obstacle Avoidance	45
3.2.4 Another Example: Two Buses in a Single Lane	49
3.3 State Machines for Different Challenge Events	55
3.3.1 Macrostates: Highway, City, and Off-Road Driving	55
3.3.2 The Demo '97 State Machine	57
3.3.3 Grand Challenge 2 State Machine	61
3.3.4 The Urban Challenge State Machine	64
References	67

CHAPTER 4

Sensors, Estimation, and Sensor Fusion	69
4.1 Sensor Characteristics	69
4.2 Vehicle Internal State Sensing	70
4.2.1 OEM Vehicle Sensors	70
4.2.2 Global Positioning System (GPS)	71
4.2.3 Inertial Measurements	80
4.2.4 Magnetic Compass (Magnetometer)	81
4.3 External World Sensing	84
4.3.1 Radar	85
4.3.2 LIDAR	86
4.3.3 Image Processing Sensors	88
4.3.4 Cooperative Infrastructure Technologies	93
4.4 Estimation	95
4.4.1 An Introduction to the Kalman Filter	95
4.4.2 Example	97
4.4.3 Another Example of Kalman Filters: Vehicle Tracking for Crash Avoidance	99
4.5 Sensor Fusion	101
4.5.1 Vehicle Localization (Position and Orientation)	101
4.5.2 External Environment Sensing	103
4.5.3 Occupancy Maps and an Off-Road Vehicle	106
4.5.4 Cluster Tracking and an On-Road Urban Vehicle	117
4.6 Situational Awareness	133
4.6.1 Structure of a Situation Analysis Module	134
4.6.2 Road and Lane Model Generation	136
4.6.3 Intersection Generation	140
4.6.4 Primitives	141

4.6.5	Track Classification	143
4.6.6	Sample Results	147
	References	147

CHAPTER 5

	Examples of Autonomy	149
5.1	Cruise Control	149
5.1.1	Background	150
5.1.2	Speed Control with an Engine Model	151
5.1.3	More Complex Systems	158
5.2	Antilock-Brake Systems	161
5.2.1	Background	161
5.2.2	Slip	162
5.2.3	An ABS System	165
5.3	Steering Control and Lane Following	167
5.3.1	Background	167
5.3.2	Steering Control	167
5.3.3	Lane Following	178
5.4	Parking	182
5.4.1	Local Coordinates	183
5.4.2	Parking Scenarios: General Parking Scenario and DARPA Urban Challenge Autonomous Vehicle Parking Scenario	184
5.4.3	Simulation and Experimental Results	190
	References	191

CHAPTER 6

	Maps and Path Planning	193
6.1	Map Databases	193
6.1.1	Raster Map Data	194
6.1.2	Vector Map Data	195
6.1.3	Utilizing the Map Data	196
6.2	Path Planning	198
6.2.1	Path Planning in an Off-Road Environment	199
6.2.2	An Off-Road Grid-Based Path Planning Algorithm	201
6.2.3	Other Off-Road Path Planning Approaches	204
6.2.4	An On-Road Path Planning Algorithm	206
	References	215

CHAPTER 7

	Vehicle-to-Vehicle and Vehicle-to-Infrastructure Communication	217
7.1	Introduction	217
7.2	Vehicle-to-Vehicle Communication (V2V)	220
7.3	Vehicle-to-Infrastructure Communication (V2I)	223
7.4	Communication Technologies	224
7.4.1	Unidirectional Communication Through Broadcast Radio	224
7.4.2	Cellular/Broadband	224

7.4.3	Information Showers	224
7.4.4	Narrowband Licensed 220 MHz	224
7.4.5	Dedicated Short-Range Communication (DSRC)	225
7.5	802.11p/WAVE DSRC Architecture and U.S./EU Standards	225
7.5.1	802.11P Physical Layer	227
7.5.2	1609.4 Channelization Overview	228
7.5.3	1609.3 Network Management	230
7.5.4	EU Programs and Standards Activity	231
7.6	Potential Applications in an Autonomous Vehicle	232
7.6.1	Platoons and Adaptive Cruise Control (ACC)	233
7.6.2	Merging Traffic	238
7.6.3	Urban Driving with Stop-and-Go Traffic	241
	References	244
	Selected Bibliography	245

CHAPTER 8

	Conclusions	247
8.1	Some Related Problems	247
8.1.1	Fault Tolerance	247
8.1.2	Driver Modeling	249
8.2	And the Beat Goes On	251
	References	255

	Appendix	257
A.1	Two-Wheel Vehicle (Bicycle) Model	257
A.2	Full Vehicle Model Without Engine Dynamics	260
A.2.1	Lateral, Longitudinal, and Yaw Dynamics	260
A.2.2	Suspension Forces and Tire Dynamics	263
A.2.3	Tire Forces	264

	About the Authors	269
	Index	271