AUTOMOTIVE CONTROL SYSTEMS

This engineering textbook is designed to introduce advanced control systems for vehicles, including advanced automotive concepts and the next generation of vehicles for Intelligent Transportation Systems (ITS). For each automotive-control problem considered, the authors emphasize the physics and underlying principles behind the control-system concept and design. This is an exciting and rapidly developing field for which many articles and reports exist but no modern unifying text. An extensive list of references is provided at the end of each chapter for all topics covered. This is currently the only textbook, including problems and examples, that covers and integrates the topics of automotive powertrain control, vehicle control, and ITS. The emphasis is on fundamental concepts and methods for automotive control systems rather than the rapidly changing specific technologies. Many of the text examples, as well as the end-of-chapter problems, require the use of MATLAB and/or Simulink.

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Contents

Preface *page* ix

PART I INTRODUCTION AND BACKGROUND

1 **Introduction** . . . 3
- 1.1 Motivation, Background, and Overview 3
- 1.2 Overview of Automotive Control Systems 7

2 **Automotive Control-System Design Process** . . . 21
- 2.1 Introduction 21
- 2.2 Identifying the Control Requirements 22

3 **Review of Engine Modeling** . . . 33
- 3.1 Engine Operations 33
- 3.2 Engine Control Loops 37
- 3.3 Control-Oriented Engine Modeling 42

4 **Review of Vehicle Dynamics** . . . 54
- 4.1 Coordinates and Notation for Vehicle Dynamics 54
- 4.2 Longitudinal Vehicle Motion 58
- 4.3 Lateral Vehicle Motion 64
- 4.4 Vertical Vehicle Motion 77

5 **Human Factors and Driver Modeling** . . . 93
- 5.1 Human Factors in Vehicle Automation 93
- 5.2 Driver Modeling 101

PART II POWERTRAIN CONTROL SYSTEMS

6 **Air–Fuel Ratio Control** . . . 119
- 6.1 Lambda Control 119
- 6.2 PI Control of a First-Order System with Delay 120

7 **Control of Spark Timing** . . . 124
- 7.1 Knock Control 124

8 **Idle-Speed Control** 126

9 **Transmission Control** 131
9.1 Electronic Transmission Control 131
9.2 Clutch Control for AWD 133

10 **Control of Hybrid Vehicles** 148
10.1 Series, Parallel, and Split Hybrid Configurations 148
10.2 Hybrid Vehicle-Control Hierarchy 152
10.3 Control Concepts for Series Hybrids 157
10.4 Control Concepts for Parallel Hybrids 166
10.5 Control Concept for Split Hybrids 177
10.6 Feedback-Based Supervisory Controller for PHEVs 178

11 **Modeling and Control of Fuel Cells for Vehicles** 187
11.1 Introduction 187
11.2 Modeling of Fuel-Cell Systems 189
11.3 Control of Fuel-Cell Systems 196
11.4 Control of Fuel-Cell Vehicles 201
11.5 Parametric Design Considerations 205

PART III VEHICLE CONTROL SYSTEMS

12 **Cruise and Headway Control** 213
12.1 Cruise-Controller Design 213
12.2 Autonomous Cruise Control: Speed and Headway Control 224

13 **Antilock Brake and Traction-Control Systems** 232
13.1 Modeling 234
13.2 Antilock Braking Systems 236
13.3 Traction Control 247

14 **Vehicle Stability Control** 257
14.1 Introduction 258
14.2 Linear Vehicle Model 261
14.3 Nonlinear Vehicle Model 263
14.4 VSC Design Principles 266

15 **Four-Wheel Steering** 272
15.1 Basic Properties 272
15.2 Goals of 4WS Algorithms 274

16 **Active Suspensions** 287
16.1 Optimal Active Suspension for Single-DOF Model 288
16.2 Optimal Active Suspension for Two-DOF Model 290
16.3 Optimal Active Suspension with State Estimation 294

PART IV INTELLIGENT TRANSPORTATION SYSTEMS

17 **Overview of Intelligent Transportation Systems** 309
17.1 Advanced Traffic Management Systems 310
17.2 Advanced Traveler Information Systems 312
17.3 Commercial Vehicle Operations 314
17.4 Advanced Vehicle-Control Systems 314

18 **Preventing Collisions** 322
18.1 Active Safety Technologies 322
18.2 Collision Detection and Avoidance 322

19 **Longitudinal Motion Control and Platoons** 332
19.1 Site-Specific Information 332
19.2 Platooning 337
19.3 String Stability 343

20 **Automated Steering and Lateral Control** 348
20.1 Lane Sensing 348
20.2 Automated Lane-Following Control 352
20.3 Automated Lane-Change Control 356

APPENDICES

Appendix A: **Review of Control-Theory Fundamentals** 363
A.1 Review of Feedback Control 363
A.2 Mathematical Background and Design Techniques 370

Appendix B: **Two-Mass Three-Degree-of-Freedom Vehicle Lateral/Yaw/Roll Model** 385

Index 391

Preface

This textbook is organized in four major parts as follows:

I. *Introduction and Background* is an introduction to the topic of automotive control systems and a review of background material on engine modeling, vehicle dynamics, and human factors.
II. *Powertrain Control Systems* includes topics such as air–fuel ratio control, idle-speed control, spark-timing control, control of transmissions, control of hybrid-electric vehicles, and fuel-cell vehicle control.
III. *Vehicle Control Systems* covers cruise control and headway-control systems, traction-control systems (including antilock brakes), active suspensions, vehicle-stability control, and four-wheel steering.
IV. *Intelligent Transportation Systems (ITS)* includes an overview of ITS technologies, collision detection and avoidance systems, automated highways, platooning, and automated steering.

With multiple chapters in each part, this textbook contains sufficient material for a one-semester course on automotive control systems. The coverage of the material is at the first-year graduate or advanced undergraduate level in engineering. It is assumed that students have a basic undergraduate-level background in dynamics, automatic control, and automotive engineering.

This textbook is written for engineering students who are interested in participating in the development of advanced control systems for vehicles, including advanced automotive concepts and the next generation of vehicles for ITS. This is an exciting and rapidly developing field for which numerous articles and reports exist. An extensive list of references, therefore, is provided at the end of each chapter for all topics covered. Due to the breadth of topics treated, the reference lists are by no means comprehensive, and new studies are always appearing. However, the lists cover many major contributions and the basic concepts in each sub-area. This textbook is intended to provide a framework for unifying the vast literature represented by the references listed at the end of each chapter. It is currently the only textbook, including problems and examples, that covers and integrates the topics of automotive powertrain control, vehicle control, and ITS.

The emphasis is on fundamental concepts and methods for automotive control systems rather than the rapidly changing specific technologies. For each

automotive-control problem considered, we emphasize the physics and underlying principles behind the control-system concept and design. Any one of the many topics covered (e.g., engine control, vehicle-stability control, or platooning) could be discussed in more detail. However, rather than treating a specific control problem in its full complexity, we use each automotive control application as an opportunity to focus on a key engineering aspect of the control-design problem. For example, we discuss the importance of regulating the air–fuel ratio in engine control, the benefits for vehicle dynamics of reducing the vehicle side-slip angle in four-wheel steering and vehicle-stability control, the importance of predictive/preview action in the material on driver modeling, the concept of string stability for platoons and autonomous cruise-control systems, and the role of risk homeostasis in active-safety-systems design.

We also use various automotive-control applications to focus on specific control methodologies. For example, the Smith predictor for control of time-delay systems is introduced in air–fuel ratio control; linear quadratic optimal estimation and control is introduced for active suspensions; adaptive control using recursive least squares estimation is introduced in the chapter on cruise-control systems; and sliding-mode control is introduced in the discussion of traction-control systems. However, all of these methods can be applied to many other automotive-control problems.

End-of-chapter problems are included and many are used in our courses as homework and/or examination problems. Throughout the text, we include examples to illustrate key points. Many of these examples, as well as the end-of-chapter problems, require the use of MATLAB and/or Simulink. It is assumed that students are familiar with these computational engineering tools; for those who are not, we highly recommend the *Control Tutorials for MATLAB and Simulink* Web site (www.engin.umich.edu/class/ctms) for self-study.

This textbook is based on course notes originally developed by A. Galip Ulsoy during the mid-1990s, then refined and added to by both Ulsoy and Huei Peng during a period of fifteen years of teaching this material to beginning graduate students at the University of Michigan, Ann Arbor. The students are primarily from mechanical engineering disciplines, but students with a suitable background from other engineering disciplines also are included, as well as practicing engineers in the automotive industry who take the course through distance-learning programs and short courses.

We sincerely thank all of our former students for their useful feedback, which led to many improvements in and additions to this material. We also welcome your comments so that we can continue to improve future versions. The current textbook was rewritten extensively from those course notes in collaboration with Melih Çakmakcı, who was not only a former student who took the course but also has worked in the automotive industry as a control engineer for a decade. He brings an additional perspective to the material from his extensive industrial experience.

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