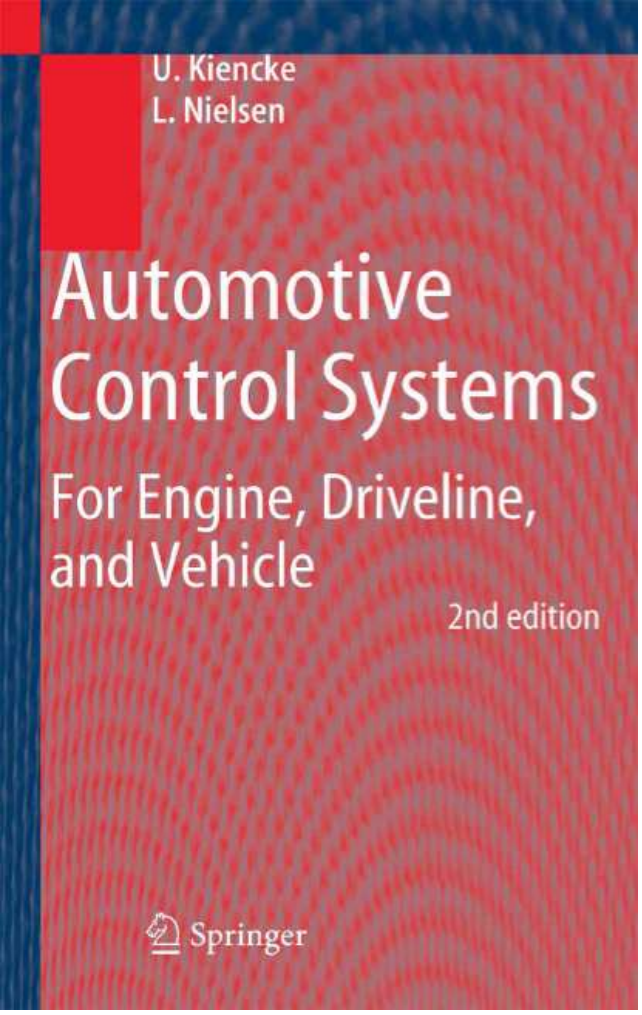
U. Kiencke
L. Nielsen
Automotive
Control Systems
For Engine, Driveline,
and Vehicle
2nd edition
Springer

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Second edition

With 345 figures and 13 tables

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To Margarete and Ingrid

Preface to the second edition

Since the first edition of this book was published, already five years have passed, and during this period research on automotive control has flourished, and at the same time, the amount of industrial applications and products have also prospered. This means that there was a rich flora of possibilities regarding the selection of material when planning the second edition. In this process new topics have been added, important fields have been deepened, and in order to keep the number of pages down, sections of limited interest have been eliminated.

In the selection of the new material we have concentrated on subjects that are both of current interest and importance, but at the same time are subjects that also contribute to a better understanding of basic processes and theories. The new material includes two completely new chapters: Diesel Engine Modeling and Diagnosis.

In driveline control a new section on Anti-Jerk Control has been added. Large parts of Vehicle Dynamics and Control have been rewritten, which significantly improves the presentation of that material. Further, in this second edition, we have hopefully corrected most of the errors in the first edition, reviewed the nomenclature, and in order to facilitate to work with this book, added an index.

The level of presentation has been thought trough to be suited for students at late undergraduate level or at early graduate level. The so called Bologna process is influencing universities in Europe at this moment, and in that perspective this book should be well suited for a course at the two year Masters level.

We like to thank Dr. Dara Torkzadeh and Thomas Rambow for their contributions in Diesel Engine Modeling, Dr. Mattias Nyberg for his work in Diagnosis, Julian Baumann for his participation in Anti-Jerking Control and Dr. Marcus Hiemer as well as Jörg Barrho for their work in Vehicle Dynamics and reviewing this book.

November 2004

Uwe Kiencke Lars Nielsen

Preface to the first edition

Automotive control has become a driving factor in automotive innovation over the last twenty five years. In order to meet the enhanced requirements for lower fuel consumption, lower exhaust emissions, improved safety as well as comfort and convenience functions, automotive control had to be applied.

In any area of technology, control design is an interplay between reality, physics, modeling, and design methods. This is also true in automotive control, and there has been extensive work done in research and development leading to a number of descriptions, models, and design methodologies suited for control.

Goal of the book

Our purpose of writing a book on Automotive Control is to present this interplay between thermodynamics, basics of engine operation, vehicle mechanics as well as parameter estimation and automotive control approaches.

There are several good books available on the separate disciplines (some of the major references are in German). However, up until now there has not been a text available that explores more deeply the connections between reality, measurements, models and control design.

It has been natural for us to treat all the major aspects of automotive control in the same book. This means that we cover engine, driveline, and complete vehicle. One reason is that there are similarities in methodology when analyzing and designing automotive control systems. This includes the point of view of finding models of suitable complexity and expressiveness. Another, perhaps more important, reason is that there is a strong trend that engine control, driveline control, and vehicle control rather than being separate will be more and more integrated, so that overall vehicle optimization is possible.

It has also been important to us to show real measurements. This gives a reader the possibility to see how models are approximations of reality, and

to judge the modeling assumptions. A consequence of this approach is that we have selected to treat systems that are close to some of those utilized in actual vehicles, rather than discussing speculative systems or presenting purely theoretical results.

Intended readers

This book should enable control engineers to understand engine and vehicle models necessary for controller design and should introduce mechanical engineers into vehicle-specific signal processing and automatic control.

In fact, our inspiration to write the book came from this. We are both members of the IFAC technical committee on Automotive Control (with the first author being the chairman). We met there and also at SAE meetings, and we saw the potential value of bridging a gap that was obvious to us. However, even more important to us is to share some of the fun and excitement that goes into the area of Automotive Control Systems and thus give it the attention it deserves.

Organization of the book

The outline of the book starts with engines, continues with drivelines, and finally deals with the vehicle.

Chapters 2 to 4 treat engines with regard to basics, thermodynamics, models, control, and advanced concepts. All the major control systems and their design are treated. The thermodynamic models in Chapter 2 deal with parameters that vary under one cycle and the resolution of interest is typically one crank angle degree, whereas the time scales of mean value models are in the order of 1 to several engine cycles, and the variation in variables that are considered are also averaged over one or several cycles. These models form the basis for understanding the complex phenomena that influence the engine operation, efficiency and emissions. They also serve the purpose of describing the properties influencing control design and performance in Chapters 3 and 5.

The driveline (engine, clutch, transmission, shafts, and wheels) which is a fundamental part of a vehicle is the topic in Chapter 7. Since the parts are elastic, mechanical resonances may occur. The handling of such resonances is basic for functionality and driveability, but is also important for reducing mechanical stress and noise. Two important modes of driveline control that are treated are driveline speed control and driveline torque control, having their applications in cruise control and automatic gear shifting control.

Vehicle dynamics control systems help the driver to perform the task of keeping the vehicle on the road in a safe manner. These systems are thus often safety-oriented, which means that they only interact in situations where they can reduce the possibility of an accident, but then they affect the immediate behavior of the vehicle within fractions of a second. Some systems are also used for improving the comfort of the driver. The performance of a vehicle, regarding the motions coming from accelerating, braking, cornering, or ride, is mainly a response to the forces imposed on the vehicle from the tire-road contact. Much of study of vehicle dynamics is a study on why and how these forces are produced and how they can be effectively understood and treated in simplified models.

The basics of these models and some associated control systems are presented in Chapters 8 to 10.

Chapter 11 is the exception from that all the systems and principles in this book is close to some of those utilized in actual vehicles. The reason is that road and driver modeling is part of simulation design rather than part of a vehicle. Nevertheless, it is important to realize that road and driver models are important parts in the design cycle of automotive systems design due to the importance of advanced simulation.

Background and use of the book

The material in this book has been used in courses at the universities of Karlsruhe, Germany and Linköping, Sweden. It is well suited for the later stages (third or fourth year) of the engineering programs at our technical institutes ("Diploma-engineer", "Master of Science").

The book, to a large extent, covers the basic material needed, but of course it is advantageous to have a background from basic undergraduate courses in automatic control, signals and systems, mechanics, and physics.

The course lay-out includes problem-solving sessions and laboratory experiments. The laboratory assignments typically include measurements, building models of the type treated in the book, and finally designing controllers and simulating them. Here students with more background, for example in modern control, can do more elaborate designs. This is also the case when the book is used in an introductory graduate course.

The authors

Dr. Kiencke's experience in this field started in the early nineteen seventies when developing adaptive lambda control and knock control at Robert Bosch Corporation. In the following years more complex approaches for engine modelling [2], [22] and controller design [63] were published. At that time he headed a team that developed the vehicle communication network "Controller Area Network (CAN)" [67]. Networking allowed to combine formerly stand-alone control schemes into an integrated vehicle control system. In the early nineteen nineties he joined the University of Karlsruhe in Germany where he could intensify engine and vehicle dynmaic control research.

Dr. Nielsen has more than fifteen years background in academic mechatronics research (obtaining a good start at the Department of Automatic Control in Lund, Sweden). He has during that time continuously collaborated with industry, and has lead joint research projects with Scania AB, Mecel AB, Saab Automobile AB, Volvo AB, and DaimlerChrysler. He is since 1992 holder of the chair Sten Gustafsson professor of vehicular systems at Linköping University in Sweden.

Acknowledgments

The control systems presented were mostly developed within a team. Therefore the first author would like to thank especially the following cooperation partners: Dr. Martin Zechall in lambda (air-fuel ratio) control, Dr. Böning in knock control

and engine map optimization, Alfred Schutz in engine idle speed control, Heinz Leiber in ABS braking control, Dr. Michael Henn in misfire detection, Dr. Achim Daiss in vehicle modelling and identification and Dr. Rajjid Majjad in road and driver modelling. It was a great pleasure to cooperate with these people and it created many friendships. The second author is especially indebted to Magnus Petterssson for joint work in driveline control, and to Lars Eriksson for joint work in engine modelling and control. Also Lars-Gunnar Hedström, Jan Nytomt, and Jan Dellrud deserves special mentioning as research dedicated industrial partners.

Furthermore we both thank Christopher Riegel, Jochen Schöntaler, Dara Torkzadeh, and Dr. Tracy Dalton for their tremendous effort to translate and revise parts of the book, as well as Dr. Dietrich Merkle as a publisher.

Last but not least we to thank our families and especially our wives Margarete and Ingrid for tolerating that so much weekend and vacation time was dedicated to this book.

Being in November 1999 looking forward to the next millennium, we hope that readers will share some of the excitement that comes along with Automotive Control Systems.

Uwe Kiencke Lars Nielsen