

INTEGRATED VEHICLE DYNAMICS AND CONTROL

Wuwei Chen | Hansong Xiao | Qidong Wang | Linfeng Zhao | Maofei Zhu



WILEY

INTEGRATED VEHICLE DYNAMICS AND CONTROL

INTEGRATED VEHICLE DYNAMICS AND CONTROL

Professor Wuwei Chen

Hefei University of Technology, China

Dr. Hansong Xiao

Hanergy Product Development Group, China

Professor Qidong Wang

Anhui University of Science and Technology, China

Dr. Linfeng Zhao

Hefei University of Technology, China

Dr. Maofei Zhu

Hefei Institutes of Physical Science, Chinese Academy of Sciences, China

WILEY

This edition first published 2016

© 2016 John Wiley & Sons Singapore Pte. Ltd

Registered Office

John Wiley & Sons Singapore Pte. Ltd, 1 Fusionopolis Walk, #07-01 Solaris South Tower, Singapore 138628.

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com.

The right of the author to be identified as the author of this work has been asserted in accordance with the Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by the UK Copyright, Designs and Patents Act 1988, without the prior permission of the publisher.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book

Limit of Liability/Disclaimer of Warranty: While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. It is sold on the understanding that the publisher is not engaged in rendering professional services and neither the publisher nor the author shall be liable for damages arising herefrom. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

Library of Congress Cataloging-in-Publication data applied for

ISBN: 9781118379998

A catalogue record for this book is available from the British Library.

Cover Image: © gettyimages.com

Set in 10/12.5pt Times by SPi Global, Pondicherry, India

Contents

Preface	xi
1 Basic Knowledge of Vehicle System Dynamics	1
1.1 Traditional Methods of Formulating Vehicle Dynamics Equations	1
1.1.1 <i>Newtonian Mechanics</i>	2
1.1.2 <i>Analytical Mechanics</i>	3
1.2 Dynamics of Rigid Multibody Systems	3
1.2.1 <i>Birth and Development</i>	3
1.2.2 <i>Theories and Methods of Multi-Rigid Body System Dynamics</i>	5
1.2.3 <i>An Example of the Application of Multi-Rigid Body Dynamics Method in Vehicle System Modeling</i>	8
1.3 Flexible Multibody Dynamics	12
References	13
2 Tyre Dynamics	15
2.1 Tyre Models	15
2.1.1 <i>Terminology and Concepts</i>	15
2.1.2 <i>Tyre Model</i>	17
2.2 Tyre Longitudinal Mechanical Properties	19
2.2.1 <i>Tyre Rolling Resistance</i>	20
2.2.2 <i>Road Resistance</i>	21
2.2.3 <i>Tyre Slip Resistance</i>	23
2.2.4 <i>Overall Rolling Resistance of the Tyres</i>	23
2.2.5 <i>Rolling Resistance Coefficient</i>	24
2.3 Vertical Mechanical Properties of Tyres	26
2.4 Lateral Mechanical Properties of Tyres	29
2.5 Mechanical Properties of Tyres in Combined Conditions	30
References	32
3 Longitudinal Vehicle Dynamics and Control	33
3.1 Longitudinal Vehicle Dynamics Equations	33
3.1.1 <i>Longitudinal Force Analysis</i>	33
3.1.2 <i>Longitudinal Vehicle Dynamics Equation</i>	34

3.2	Driving Resistance	35
3.2.1	<i>Aerodynamic Drag</i>	36
3.2.2	<i>Ramp Resistance</i>	36
3.2.3	<i>Inertial Resistance</i>	37
3.3	Anti-lock Braking System	38
3.3.1	<i>Introduction</i>	38
3.3.2	<i>Basic Structure and Working Principle</i>	38
3.3.3	<i>Design of an Anti-lock Braking System</i>	40
3.4	Traction Control System	48
3.4.1	<i>Introduction</i>	48
3.4.2	<i>Control Techniques of TCS</i>	49
3.4.3	<i>TCS Control Strategy</i>	51
3.4.4	<i>Traction Control System Modeling and Simulation</i>	53
3.5	Vehicle Stability Control	54
3.5.1	<i>Basic Principle of VSC</i>	55
3.5.2	<i>Structure of a VSC System</i>	56
3.5.3	<i>Control Methods to Improve Vehicle Stability</i>	59
3.5.4	<i>Selection of the Control Variables</i>	60
3.5.5	<i>Control System Structure</i>	64
3.5.6	<i>The Dynamics Models</i>	64
3.5.7	<i>Setting of the Target Values for the Control Variables</i>	67
3.5.8	<i>Calculation of the Nominal Yaw Moment and Control</i>	68
	Appendix	75
	References	75
4	Vertical Vehicle Dynamics and Control	77
4.1	Vertical Dynamics Models	77
4.1.1	<i>Introduction</i>	77
4.1.2	<i>Half-vehicle Model</i>	78
4.2	Input Models of the Road's Surface	81
4.2.1	<i>Frequency-domain Models</i>	81
4.2.2	<i>Time Domain Models</i>	83
4.3	Design of a Semi-active Suspension System	84
4.3.1	<i>Dynamic Model of a Semi-active Suspension System</i>	85
4.3.2	<i>Integrated Optimization Design of a Semi-active Suspension System</i>	87
4.3.3	<i>The Realization of the Integrated Optimization Method</i>	88
4.3.4	<i>Implementation of the Genetic Algorithm</i>	90
4.3.5	<i>LQG Controller Design</i>	91
4.3.6	<i>Simulations and Result Analysis</i>	92
4.4	Time-lag Problem and its Control of a Semi-active Suspension	95
4.4.1	<i>Causes and Impacts of Time-lag</i>	96
4.4.2	<i>Time-lag Variable Structure Control of an MR (Magneto-Rheological) Semi-active Suspension</i>	98
4.4.3	<i>Simulation Results and Analysis</i>	103
4.4.4	<i>Experiment Validation</i>	108

4.5	Design of an Active Suspension System	110
4.5.1	<i>The Dynamic Model of an Active Suspension System</i>	111
4.5.2	<i>Design of the Control Scheme</i>	112
4.5.3	<i>Multi-objective Mixed H_2/H_∞ Control</i>	114
4.5.4	<i>Simulation Study</i>	116
4.6	Order-reduction Study of an Active Suspension Controller	119
4.6.1	<i>Full Vehicle Model with 7 Degrees of Freedom</i>	122
4.6.2	<i>Controller Design</i>	124
4.6.3	<i>Controller Order-reduction</i>	125
4.6.4	<i>Simulation Analysis</i>	129
	References	133
5	Lateral Vehicle Dynamics and Control	135
5.1	General Equations of Lateral Vehicle Dynamics	135
5.2	Handling and Stability Analysis	137
5.2.1	<i>Steady State Response (Steady Steering)</i>	137
5.2.2	<i>Transient Response</i>	140
5.2.3	<i>The Frequency Response Characteristics of Yaw Rate</i>	144
5.3	Handling Stability Evaluations	144
5.3.1	<i>Subjective Evaluation Contents</i>	144
5.3.2	<i>Experimental Evaluation Contents</i>	144
5.4	Four-wheel Steering System and Control	145
5.4.1	<i>Control Objectives of the Four-wheel Steering Vehicle</i>	146
5.4.2	<i>Design of a Four-wheel Steering Control System</i>	146
5.4.3	<i>Multi-body Dynamics Modeling of a Four-wheel Steering Vehicle</i>	150
5.4.4	<i>Simulation Results and Analysis</i>	152
5.5	Electric Power Steering System and Control Strategy	152
5.5.1	<i>EPS Model</i>	154
5.5.2	<i>Steering Torque Model of the Steering Pinion</i>	155
5.5.3	<i>The Estimation Algorithm of the Road Adhesion Coefficient</i>	159
5.5.4	<i>Design of the Control Strategy</i>	160
5.5.5	<i>Simulation and Analysis</i>	163
5.5.6	<i>Experimental Study</i>	165
5.6	Automatic Lane Keeping System	167
5.6.1	<i>Control System Design</i>	167
5.6.2	<i>Desired Yaw Rate Generation</i>	168
5.6.3	<i>Desired Yaw Rate Tracking Control</i>	171
5.6.4	<i>Simulation and Analysis</i>	173
5.6.5	<i>Experimental Verification</i>	175
	References	180
6	System Coupling Mechanism and Vehicle Dynamic Model	183
6.1	Overview of Vehicle Dynamic Model	183
6.2	Analysis of the Chassis Coupling Mechanisms	184
6.2.1	<i>Coupling of Tyre Forces</i>	184
6.2.2	<i>Coupling of the Dynamic Load Distribution</i>	185

6.2.3	<i>Coupling of Movement Relationship</i>	185
6.2.4	<i>Coupling of Structure Parameters and Control Parameters</i>	186
6.3	Dynamic Model of the Nonlinear Coupling for the Integrated Controls of a Vehicle	186
6.4	Simulation Analysis	191
6.4.1	<i>Simulation</i>	191
6.4.2	<i>Results Analysis</i>	192
	References	199
7	Integrated Vehicle Dynamics Control: Centralized Control Architecture	201
7.1	Principles of Integrated Vehicle Dynamics Control	201
7.2	Integrated Control of Vehicle Stability Control Systems (VSC)	204
7.2.1	<i>Sideslip Angle Control</i>	204
7.2.2	<i>Estimation of the Road Adhesion Coefficient</i>	218
7.3	Integrated Control of Active Suspension System (ASS) and Vehicle Stability Control System (VSC) using Decoupling Control Method	226
7.3.1	<i>Vehicle Dynamic Model</i>	227
7.3.2	<i>2-DOF Reference Model</i>	228
7.3.3	<i>Lateral Force Model</i>	229
7.3.4	<i>Integrated System Control Model</i>	229
7.3.5	<i>Design of the Decoupling Control System</i>	230
7.3.6	<i>Calculation of the Relative Degree</i>	230
7.3.7	<i>Design of the Input/Output Decoupling Controller</i>	232
7.3.8	<i>Design of the Disturbance Decoupling Controller</i>	233
7.3.9	<i>Design of the Closed Loop Controller</i>	233
7.3.10	<i>Design of the ASS Controller</i>	233
7.3.11	<i>Design of the VSC Controller</i>	234
7.3.12	<i>Simulation Investigation</i>	236
7.3.13	<i>Experimental Study</i>	240
7.4	Integrated Control of an Active Suspension System (ASS) and Electric Power Steering System (EPS) using H_{∞} Control Method	240
7.4.1	<i>Vehicle Dynamic Model</i>	243
7.4.2	<i>EPS Model</i>	243
7.4.3	<i>Design of Integrated Control System</i>	245
7.4.4	<i>Simulation Investigation</i>	246
7.5	Integrated Control of Active Suspension System (ASS) and Electric Power Steering System (EPS) using the Predictive Control Method	249
7.5.1	<i>Designing a Predictive Control System</i>	249
7.5.2	<i>Boundary Conditions</i>	250
7.5.3	<i>Simulation Investigation</i>	251
7.6	Integrated Control of the Active Suspension System (ASS) and Electric Power Steering System (EPS) using a Self-adaptive Control Method	253
7.6.1	<i>Parameter Estimation of a Multivariable System</i>	253
7.6.2	<i>Design of the Multivariable Generalized Least Square Controller</i>	254
7.6.3	<i>Design of the Multivariable Self-adaptive Integrated Controller</i>	255
7.6.4	<i>Simulation Investigation</i>	255

