Mechatronic Systems

Mechatronic Systems

Modelling and Simulation with HDLs

Georg Pelz

Infineon Technologies, Munich, Germany

Translated by

Rachel Waddington

Member of the Institute of Translation and Interpreting



First published under the title Modellierung und Simulation mechatronischer Systeme—vom Chip zum Systementwurf mit Hardwarebeschreibungssprachen © Hüthig-Verlag, Heidelberg, 2001 All Rights reserved

Authorized translation from German language edition published by Hüthig-Verlag

Copyright © 2003 John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England

Telephone (+44) 1243 779777

Email (for orders and customer service enquiries): cs-books@wiley.co.uk Visit our Home Page on www.wileyeurope.com or www.wiley.com

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, scanning or otherwise, except under the terms of the Copyright, Designs and Patents Act 1988 or under the terms of a licence issued by the Copyright Licensing Agency Ltd, 90 Tottenham Court Road, London W1T 4LP, UK, without the permission in writing of the Publisher. Requests to the Publisher should be addressed to the Permissions Department, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England, or emailed to permreq@wiley.co.uk, or faxed to (+44) 1243 770620.

This publication is designed to provide accurate and authoritative information in regard to the subject matter covered. It is sold on the understanding that the Publisher is not engaged in rendering professional services. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

Other Wiley Editorial Offices

John Wiley & Sons Inc., 111 River Street, Hoboken, NJ 07030, USA

Jossey-Bass, 989 Market Street, San Francisco, CA 94103-1741, USA

Wiley-VCH Verlag GmbH, Boschstr. 12, D-69469 Weinheim, Germany

John Wiley & Sons Australia Ltd, 33 Park Road, Milton, Queensland 4064, Australia

John Wiley & Sons (Asia) Pte Ltd, 2 Clementi Loop #02-01, Jin Xing Distripark, Singapore 129809

John Wiley & Sons Canada Ltd, 22 Worcester Road, Etobicoke, Ontario, Canada M9W 1L1

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

Library of Congress Cataloging-in-Publication Data

Pelz, Georg, 1962-

[Modellierung und Simulation mechatronischer Systeme. English]

Mechatronic systems: modelling and simulation with HDLs / George Pelz.

p. cm.

Includes bibliographical references and index.

ISBN 0-470-84979-7 (alk. paper)

1. Mechatronics. 2. Computer hardware description languages. I. Title.

TJ163.12.P4513 2003 621-dc21

2002192433

British Library Cataloguing in Publication Data

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

ISBN 0-470-84979-7

Typeset in 10.5/13pt Times by Laserwords Private Limited, Chennai, India Printed and bound in Great Britain by Antony Rowe Ltd, Chippenham, Wiltshire This book is printed on acid-free paper responsibly manufactured from sustainable forestry in which at least two trees are planted for each one used for paper production.

Contents

Pr	reface		
1	Objective and Motivation		
	1.1	Introduction	1
2	Pri	nciples of Modelling and Simulation	5
	2.1	Introduction	5
	2.2	Model Categories	8
	2.3	Fields of Application	9
		2.3.1 Introduction	9
		2.3.2 Bottom-up design	9
		2.3.3 Top-down design	10
		2.3.4 Relationship of design strategies to modelling	12
		2.3.5 Modelling for the specification	12
		2.3.6 Modelling for the design	13
	2.4	Model Development	14
		2.4.1 Introduction	14
		2.4.2 Structural modelling	16
		2.4.3 Physical modelling	18
		2.4.4 Experimental modelling	20
	2.5 Model Verification and Validation		24
		2.5.1 Introduction	24
		2.5.2 Model verification	24
		2.5.3 Model validation	27
	2.6	Model Simplification	32
	2.7	Simulators and Simulation	33
		2.7.1 Introduction	33
		2.7.2 Circuit simulation	33
		2.7.3 Logic simulation	34
		2.7.4 Multibody simulation	35
		2.7.5 Block diagram simulation	36

vi CONTENTS

		2.7.6 Finite element simulation	36	
		2.7.7 Software simulation	36	
	2.8	Summary	37	
3	Mo	delling and Simulation of Mixed Systems	39	
	3.1	Introduction	39	
	3.2	Electronics and Mechanics	40	
		3.2.1 Introduction	40	
		3.2.2 Analogies	41	
		3.2.3 Limits of the analogies	43	
		3.2.4 Differences between electronics and mechanics	44	
	3.3	Model Transformation	45	
		3.3.1 Introduction	45	
		3.3.2 Circuit simulation	45	
		3.3.3 Logic/Petri net simulation	47	
		3.3.4 Multibody simulation	50	
		3.3.5 Finite-element simulation	51	
		3.3.6 Evaluation of the model transformation	51	
	3.4	Domain-Independent Description Forms	52	
		3.4.1 Bond graphs	52	
		3.4.2 Block diagrams	54	
		3.4.3 Modelling languages for physical systems	55	
		3.4.4 Evaluation of domain-independent description forms	57	
	3.5	Simulator Coupling	58	
		3.5.1 Introduction	58	
		3.5.2 Simulator backplane	58	
		3.5.3 Examples of the simulator coupling	60	
		3.5.4 Evaluation	62	
	3.6	Summary	62	
4	Mo	Iodelling in Hardware Description Languages		
	4.1	Introduction	63	
	4.2	Fields of Application	65	
		4.2.1 Formulation of specification and design	65	
		4.2.2 Validation of specifications and verification of designs	65	
		4.2.3 Automatic synthesis	66	
	4.3	Characterisation of Hardware Description Languages	66	
	4.4	Languages	68	
	4.5	Modelling Paradigms	69	

CONTENTS	vii

			_	
		4.5.1 Introduction	69	
		4.5.2 Structural and behaviour-oriented modelling	70	
		4.5.3 Digital modelling	71	
		4.5.4 Analogue modelling	74	
	4.6	Simulation of Models in Hardware Description Languages	79	
	4.7	Summary	81	
5	Sof	Software in Hardware Description Languages		
	5.1	Introduction	83	
	5.2	Simulation of Hardware for the Running of Software	85	
	5.3	Co-simulation by Software Interpretation	85	
	5.4	Co-simulation by Software Compilation	88	
	J. T	5.4.1 Introduction	88	
		5.4.2 Software representation	89	
		5.4.3 Synchronisation	90	
		5.4.4 Example of software modelling	92	
		5.4.5 Debugging of software	98	
	5.5	Summary	98	
6	Me	Mechanics in Hardware Description Languages		
	6.1	Introduction	99	
	6.2	Multibody Mechanics	100	
		6.2.1 Introduction	100	
		6.2.2 System-oriented modelling	104	
		6.2.3 Object-oriented modelling	108	
		6.2.4 Example: wheel suspension	111	
		6.2.5 Further applications	113	
	6.3	Continuum Mechanics	115	
		6.3.1 Introduction	115	
		6.3.2 Structural modelling	116	
		6.3.3 Physical modelling	125	
		6.3.4 Experimental modelling	130	
	6.4	Summary	132	
7	Me	chatronics	135	
	7.1	Modelling of Mechatronic Systems	135	
	7.2	Demonstrator 1: Semi-Active Wheel Suspension	136	
		7.2.1 System description	136	
		7.2.2 Modelling of software	138	

viii CONTENTS

Li	Literature			189
9	Sur	nmar	y and Outlook	187
	8.4	Sumn	nary	186
		8.3.2	Modelling Simulation	183 186
		8.3.1 8.3.2	System description Modelling	183 183
	8.3		onstrator 6: Micromirror	182
		8.2.3	_	176
			Modelling	168
	8.2	8.2.1	onstrator 5: Capacitive Pressure Sensor System description	166 166
	0.2			
		8.1.2 8.1.3		164 165
		8.1.1		163
	8.1		elling Micromechatronic Systems	163
8	Micromechatronics			163
	7.0	Sumn	пагу	101
	7.6		-	161
			Acknowledgement	161
			Simulation and results Conclusion	159 160
			System modelling	158
			The virtual disk drive	157
			Circuit development for disk drives	154
		7.5.2	The disk drive	153
		7.5.1	Introduction	152
	7.5	Demo	onstrator 4: Disk Drive	152
		7.4.4	Simulation	152
			Modelling	148
			System description	148
	7.4	7.4.1		148
	7.4		onstrator 3: Camera Winder	148
		7.3.3		147
		7.3.1 7.3.2		143 145
	7.3		onstrator 2: Internal Combustion Engine with Drive Train	143
		7.2.4		140
			Modelling of mechanics	139

CONTENTS	ix
Appendix	217
Symbols	217
Abbreviations	220
Registered Trademarks	220
Index	221

Preface

Most of this work came into being during my employment at the Chair for Electron Devices and Circuits in the Electronics Engineering department of the Gerhard-Mercator University, Duisburg. Section 7.5 covers material that I have worked on for my current employer, Infineon Technologies.

At this point I would like to express my gratitude for the support that I received from many sides. My special thanks go to Prof. Dr. G. Zimmer, in whose department I was able to work continuously for many years on the subject of this book, and who helped me in many ways in the process. Moreover, I would like to thank Prof. Dr. M. Glesner for his support of the work.

I would also like to thank my colleagues at the Gerhard-Mercator University, Duisburg, the Fraunhofer Institut IMS and Infineon Technologies, who provided a great deal of assistance in the form of discussions and suggestions during the preparation of the book. The following in particular should be mentioned: Dr. J. Bielefeld, Dr. M. Leineweber, Dipl.-Ing. A. Lüdecke and Dipl.-Ing. L. Voßkämper.

Apart from the technical side, I would like to express my thanks to Tilmann Leopold. Last, but not least, I thank my family for their encouragement and support during the composition of this book.

Ebersberg, January 2003

Georg Pelz (Georg.Pelz@onlinehome.de)