Preface

Many technical processes and products in the area of mechanical and electrical engineering are showing an increasing integration of mechanics with digital electronics and information processing. This integration is between the components (hardware) and by the information-driven functions (software), resulting in integrated systems called *mechatronic systems*. Their development involves finding an optimal balance between the basic mechanical structure, sensor and actuator implementation, automatic information processing and overall control. Frequently, formerly mechanical functions are replaced by electronically controlled functions, resulting in simpler mechanical structures and increased functionality. The development of mechatronic systems opens a way to many innovative solutions and synergetic effects that are not possible with mechanics or electronics alone. This technical progress has a very large influence on a multitude of products in the area of mechanical, electrical and electronic engineering and changes the design, for example, of conventional electromechanical components, machines, vehicles and precision mechanical devices with increasing intensity.

This book is intended to give an introduction to the development of mechatronic systems, especially by considering the modeling of the dynamics of the components, their interactions and overall behavior and by describing the components of information processing from sensors through microcomputers to actuators. After considering the basic structure of integrated mechanical-electronic systems, typical tasks for the design of mechatronic systems are discussed. The design of the process and the implementation of the information-processing algorithms generally requires a precise knowledge of the static and dynamic relations between input, state and output variables

and the possibilities of influencing them by control functions. Therefore, theoretical (physical) modeling, computer-aided design methods and experimental testing (identification) methods are required.

The first part of the book describes the basics of theoretical modeling, the static and dynamic behavior of lumped parameter processes in a general form and by a unified methodology for different physical domains, like mechanics, electricity and heat. After a classification of the various process elements with regard to energy, matter or information flow, the fundamental equations for processes with energy and matter flow are stated, like balance equations, constitutive equations and phenomenological equations. Here, the analogies between the processes of different physical domains are used by applying power variables for processes with energy flows, like potentials and flows or across and through variables. Special energy balance equations are stated for mechanical and electrical processes and processes with compressible fluids, like gases and steam. For the formulation of the interconnection of the process elements with energy and mass flows, the connection laws are stated, resulting in generalized node and mesh equations. The next chapter then considers the fundamental equations for mechanical systems with moving masses, including Newton´s laws of kinetics and the principles of mechanics in the form of d´Alembert´s principle and Lagrange equations.

Then, models of mechanical systems with and without motion for a selection of mechanical machine elements are described, from mass-spring-damper systems and bearings, through rotational multi-mass systems, to friction laws. This is followed by models of electrical drives in the form of electromagnets and electrical machines, like DC and AC motors. The basic mathematical models for DC and AC motors with power electronics are developed. Based on these part models, mathematical models of power-generating and power-consuming machines are derived and their static and dynamic properties, like inherent damping, resonance effects and stability, are analyzed. Then, a chapter on the experimental identification and parameter estimation of linear and non-linear dynamic systems follows, including recursive estimators for time-varying systems, artificial neural networks and look-up table representations. Further on, models of harmonic oscillations and their identification are discussed.

The second part is dedicated to the description of the information processing components of mechatronic systems as sensors, actuators and microcomputers. Typical sensors and actuators for mechatronic systems are systematically considered and their properties and performance data are surveyed to ease their selection. In the case of actuators, detailed models of electrical, hydraulic and pneumatic actuators are described. A brief treatment of the basic structure of microcomputers, including microprocessors, microcontrollers and digital signal processors and field bus systems is given in order to obtain an overview. Various tables with technical data should give some hints for the performance of these information-processing components.

In the last chapter, some examples of the development of mechatronic systems are given, including their modeling, control and fault detection, as an industrial robot, a semi-active vehicle suspension, an electrical throttle valve and an electromechanical disc brake. These examples show some applications for the topics treated throughout the book.

Based on the mathematical models of the processes and the surveys of the components of mechatronic systems, the information processing by digital control, supervision with fault diagnosis and optimization can be implemented, which is described in other books. This then enables steps in the direction of mechatronic systems, even with some intelligent properties. Examples in the area of precision mechanical systems are automatic cameras, high-density disk storage, smart actuators, learning robots and mobile robots with automatic navigation. In the area of machines, active damping systems, magnetic bearings with unbalance compensation and fault detection, machine tools with adaptive control, fault diagnosis and maintenance on demand are typical examples. For combustion engines, increasingly more actuator systems, like variable geometry turbochargers, common rail multiple injection, variable valve camshafts, electromechanical-actuated valves and adaptive look-up tables, are developed. Automobiles with electro-hydraulic brakes, electromechanical brakes, steer-by-wire and collision avoidance control with rollover prevention are further typical mechatronic developments.

The book is a revised translation of the German version, "Mechatronische Systeme", with many extensions. It is based on several research projects and lectures at the Darmstadt University of Technology, held since 1992. The general design methodology and some parts also go back to the special research project, "Integrated mechatronic systems (IMES)", at the Darmstadt University of Technology, funded by the Deutsche Forschungsgemeinschaft, in which 11 Institutes of Electrical and Mechanical Engineering cooperated in performing 20 different innovative research projects from 1988 to 2001. The book is dedicated to graduate students of electrical and electronic engineering, mechanical engineering and computer science and practising engineers in research and development, design and manufacturing.

The author is especially grateful to his research associates, who have been helpful in compiling the material. The earlier team was mentioned in the first, German, version. The translation of the German book into English, including many additions, was performed in a combined effort by Markus Börner, Stefan Drogies, Alexander Fink, Frank Kimmich, Michael Kochem, Marco Münchhof, Jürgen Schmitt, Jochen Schaffnit, Anselm Schwarte, Harald Straky, Karsten Spreitzer, Susanne Töpfer, Crina Vlad, Marian Walter, Armin Wolfram and Christof Zosel. Sections 5.4 on AC motors, 5.6 on power electronics and 6.6 on centrifugal pumps were written by Armin Wolfram, 6.7 on automobile drivetrains by Jochen Schaffnit and 8.2.7 on speed signal analysis by Frank Kimmich. Considerable extensions to Chapter 9 on sensors was contributed by Karsten Spreitzer and to Chapter 10 on actuators by Marco

Münchhof. The examples for mechatronic systems in Chapter 12 were contributed by Michael Kochem, Markus Börner and Sascha Semmler. This assistance is highly appreciated, making it possible to publish the English version in time. The final laborious and precise text setting, including the figures and tables in camera-ready form was performed by Brigitte Hoppe. Many thanks for the patient and continuous work go to her.

Darmstadt, August 2002 Rolf Isermann

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http://www.springer.com/978-1-85233-693-6

Mechatronic Systems
Fundamentals
Isermann, R.
2005, XXI, 624 p., Hardcover
ISBN: 978-1-85233-693-6