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THE MECHATRONICS HANDBOOK

Editor-in-Chief
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**ISA—The Instrumentation, Systems,
and Automation Society**



CRC PRESS

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Library of Congress Cataloging-in-Publication Data

Catalog record is available from the Library of Congress

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International Standard Book Number 0-8493-0066-5
Printed in the United States of America 1 2 3 4 5 6 7 8 9 0

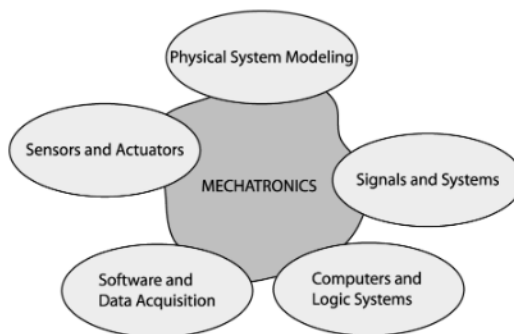
Preface

According to the original definition of mechatronics proposed by the Yasakawa Electric Company and the definitions that have appeared since, many of the engineering products designed and manufactured in the last 25 years integrating mechanical and electrical systems can be classified as *mechatronic systems*. Yet many of the engineers and researchers responsible for those products were never formally trained in mechatronics *per se*. The *Mechatronics Handbook* can serve as a reference resource for those very same design engineers to help connect their everyday experience in design with the vibrant field of mechatronics. More generally, this handbook is intended for use in research and development departments in academia, government, and industry, and as a reference source in university libraries. It can also be used as a resource for scholars interested in understanding and explaining the engineering design process. As the historical divisions between the various branches of engineering and computer science become less clearly defined, we may well find that the mechatronics specialty provides a roadmap for nontraditional engineering students studying within the traditional structure of most engineering colleges. It is evident that there is an expansion of mechatronics laboratories and classes in the university environment worldwide. This fact is reflected in the list of contributors to this handbook, including an international group of 88 academicians and engineers representing 13 countries. It is hoped that the *Mechatronics Handbook* can serve the world community as the definitive reference source in mechatronics.

Organization

The *Mechatronics Handbook* is a collection of 50 chapters covering the key elements of mechatronics:

- a. Physical Systems Modeling
- b. Sensors and Actuators
- c. Signals and Systems
- d. Computers and Logic Systems
- e. Software and Data Acquisition



Section One – Overview of Mechatronics

In the opening section, the general subject of mechatronics is defined and organized. The chapters are overview in nature and are intended to provide an introduction to the key elements of mechatronics. For readers interested in education issues related to mechatronics, this first section concludes with a discussion on new directions in the mechatronics engineering curriculum. The chapters, listed in order of appearance, are:

1. What is Mechatronics?

3. System Interfacing, Instrumentation and Control Systems
4. Microprocessor-Based Controllers and Microelectronics
5. An Introduction to Micro- and Nanotechnology
6. Mechatronics: New Directions in Nano-, Micro-, and Mini-Scale Electromechanical Systems Design, and Engineering Curriculum Development

Section Two – Physical System Modeling

The underlying mechanical and electrical mathematical models comprising most mechatronic systems are presented in this section. The discussion is intended to provide a detailed description of the process of physical system modeling, including topics on structures and materials, fluid systems, electrical systems, thermodynamic systems, rotational and translational systems, modeling issues associated with MEMS, and the physical basis of analogies in system models. The chapters, listed in order of appearance, are:

7. Modeling Electromechanical Systems
8. Structures and Materials
9. Modeling of Mechanical Systems for Mechatronics Applications
10. Fluid Power Systems
11. Electrical Engineering
12. Engineering Thermodynamics
13. Modeling and Simulation for MEMS
14. Rotational and Translational Microelectromechanical Systems: MEMS Synthesis, Microfabrication, Analysis, and Optimization
15. The Physical Basis of Analogies in Physical System Models

Section Three – Sensors and Actuators

The basics of sensors and actuators are introduced in the third section. This section begins with chapters on the important subject of time and frequency and on the subject of sensor and actuator characteristics. The remainder of the section is subdivided into two categories: sensors and actuators. The chapters include both the fundamental physical relationships and mathematical models associated with the sensor and actuator technologies. The chapters, listed in order of appearance, are:

16. Introduction to Sensors and Actuators
17. Fundamentals of Time and Frequency
18. Sensor and Actuator Characteristics
19. Sensors
 - 19.1 Linear and Rotational Sensors
 - 19.2 Acceleration Sensors
 - 19.3 Force Measurement
 - 19.4 Torque and Power Measurement
 - 19.5 Flow Measurement
 - 19.6 Temperature Measurements
 - 19.7 Distance Measuring and Proximity Sensors
 - 19.8 Light Detection, Image, and Vision Systems
 - 19.9 Integrated Micro-sensors

20. Actuators

- 20.1 Electro-mechanical Actuators
- 20.2 Electrical Machines
- 20.3 Piezoelectric Actuators
- 20.4 Hydraulic and Pneumatic Actuation Systems
- 20.5 MEMS: Microtransducers Analysis, Design and Fabrication

Section Four – Systems and Controls

An overview of signals and systems is presented in this fourth section. Since there is a significant body of readily-available material to the reader on the general subject of signals and systems, there is not an overriding need to repeat that material here. Instead, the goal of this section is to present the relevant aspects of signals and systems of special importance to the study of mechatronics. The section begins with articles on the role of control in mechatronics and on the role of modeling in mechatronic design. These chapters set the stage for the more fundamental discussions on signals and systems comprising the bulk of the material in this section. Modern aspects of control design using optimization techniques from H^2 theory, adaptive and nonlinear control, neural networks and fuzzy systems are also included as they play an important role in modern engineering system design. The section concludes with a chapter on design optimization for mechatronic systems. The chapters, listed in order of appearance, are:

- 21. The Role of Controls in Mechatronics
- 22. The Role of Modeling in Mechatronics Design
- 23. Signals and Systems
 - 23.1 Continuous- and Discrete-time Signals
 - 23.2 Z Transforms and Digital Systems
 - 23.3 Continuous- and Discrete-time State-space Models
 - 23.4 Transfer Functions and Laplace Transforms
- 24. State Space Analysis and System Properties
- 25. Response of Dynamic Systems
- 26. Root Locus Method
- 27. Frequency Response Methods
- 28. Kalman Filters as Dynamic System State Observers
- 29. Digital Signal Processing for Mechatronic Applications
- 30. Control System Design Via H^2 Optimization
- 31. Adaptive and Nonlinear Control Design
- 32. Neural Networks and Fuzzy Systems
- 33. Advanced Control of an Electrohydraulic Axis
- 34. Design Optimization of Mechatronic Systems

Section Five – Computers and Logic Systems

The development of the computer, and then the microcomputer, embedded computers, and associated information technologies and software advances, has impacted the world in a profound manner. This is especially true in mechatronics where the integration of computers with electromechanical systems has led to a new generation of smart products. The future is filled with promise of better and more intelligent

this fifth section, the focus is on computer hardware and associated issues of logic, communication, networking, architecture, fault analysis, embedded computers, and programmable logic controllers. The chapters, listed in order of appearance, are:

- 35. Introduction to Computers and Logic Systems
- 36. Logic Concepts and Design
- 37. System Interfaces
- 38. Communication and Computer Networks
- 39. Fault Analysis in Mechatronic Systems
- 40. Logic System Design
- 41. Synchronous and Asynchronous Sequential Systems
- 42. Architecture
- 43. Control with Embedded Computers and Programmable Logic Controllers

Section Six – Software and Data Acquisition

Given that computers play a central role in modern mechatronics products, it is very important to understand how data is acquired and how it makes its way into the computer for processing and logging. The final section of the *Mechatronics Handbook* is devoted to the issues surrounding computer software and data acquisition. The chapters, listed in order of appearance, are:

- 44. Introduction to Data Acquisition
- 45. Measurement Techniques: Sensors and Transducers
- 46. A/D and D/A Conversion
- 47. Signal Conditioning
- 48. Computer-Based Instrumentation Systems
- 49. Software Design and Development
- 50. Data Recording and Logging

Acknowledgments

I wish to express my heartfelt thanks to all the contributing authors. Taking time in otherwise busy and hectic schedules to author the excellent articles appearing in the *Mechatronics Handbook* is much appreciated. I also wish to thank my Advisory Board for their help in the early stages of planning the topics in the handbook.

This handbook is a result of a collaborative effort expertly managed by CRC Press. My thanks to the editorial and production staff:

Nora Konopka, Acquisitions Editor
Michael Buso, Project Coordinator
Susan Fox, Project Editor

Thanks to my friend and collaborator Professor Richard C. Dorf for his continued support and guidance. And finally, a special thanks to Lynda Bishop for managing the incoming and outgoing draft manuscripts. Her organizational skills were invaluable to this project.

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ration with an emphasis on spacecraft guidance, navigation, and control. He is currently working with NASA Johnson Space Center and the Jet Propulsion Laboratory on techniques for achieving precision landing on Mars. He is an active researcher authoring and co-authoring over 50 journal and conference papers. He was twice selected as a Faculty Fellow at the NASA Jet Propulsion Laboratory and a Welliver Faculty Fellow by The Boeing Company. Dr. Bishop co-authored *Modern Control Systems* with Prof. R. C. Dorf, and he has authored two other books entitled *Learning with LabView* and *Modern Control System Design and Analysis Using Matlab and Simulink*. He recently received the John Leland Atwood Award from the American Society of Engineering Educators and the American Institute of Aeronautics and Astronautics that is given periodically to “a leader who has made lasting and significant contributions to aerospace engineering education.”

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