
WE TRIP THE LIGHT
FANTASTIC

THE MECHATRONICS HANDBOOK

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ISA–The Instrumentation, Systems, and Automation Society

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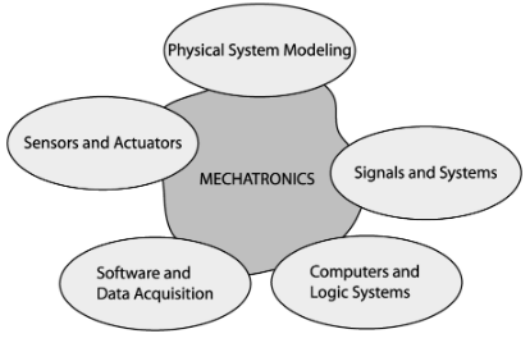
Preface

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:

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

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