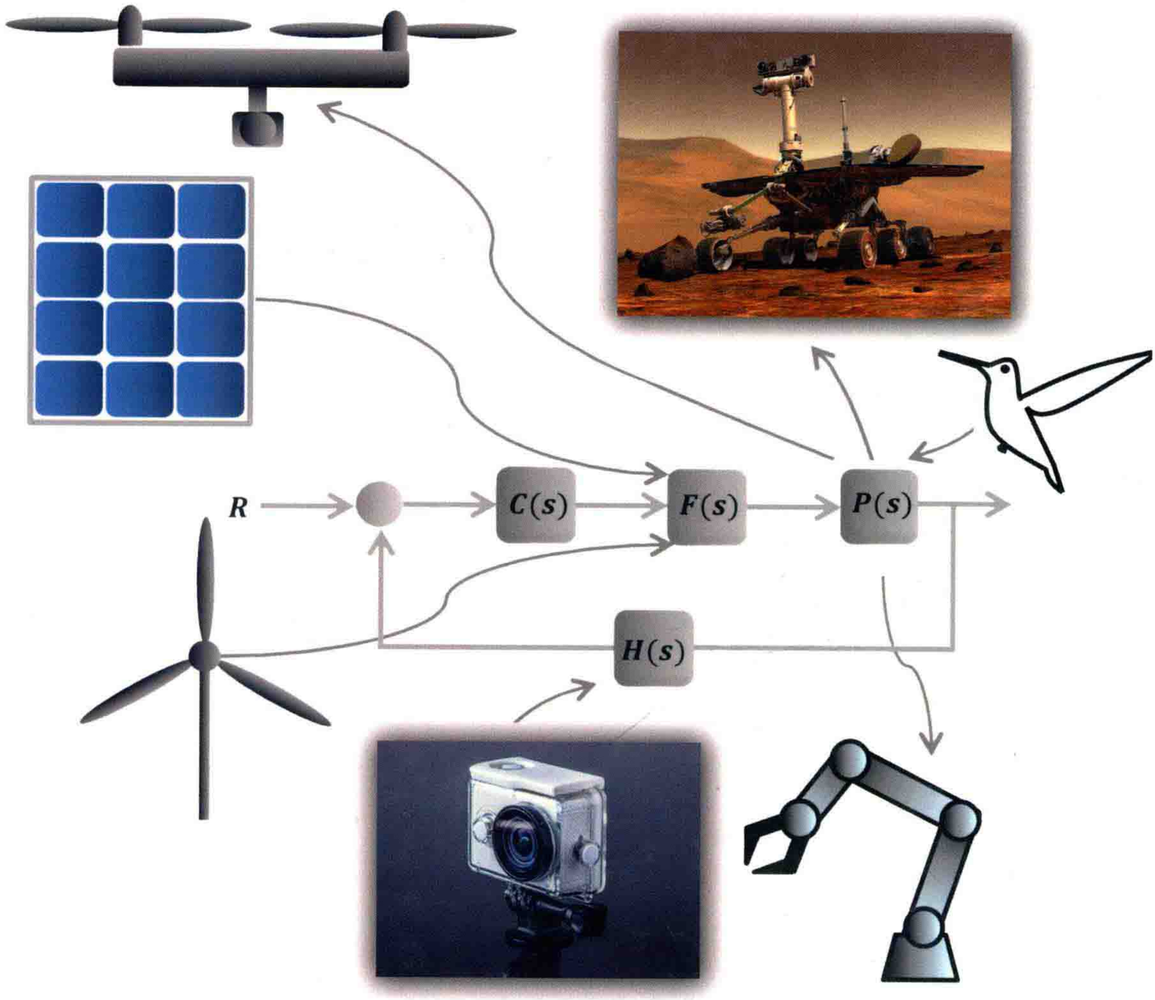
Mechatronics

Fundamentals and Applications



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Preface

With individual chapters authored by professionals in their respective topics, this book provides a convenient and up-to-date reference with information on the latest developments of mechatronics for engineers, designers, researchers, educators, and students. The presented material includes methodologies that encompass modeling, analysis, design, control, monitoring, and diagnosis of mechatronic systems and state-of-the-art mechatronic systems and technologies. The book consists of 15 chapters, grouped into two sections: fundamentals and applications. Cross-referencing is used when necessary to indicate other places in the book where further information on a particular topic is provided.

In the book, equal emphasis is given to theory and practical application. The chapters cover fundamentals and applications of mechatronic devices and systems with specific treatment of related topics, including modeling and analytical formulations, simulation methods, design approaches, control techniques, practical tools, and cutting-edge systems and applications, illustrated using examples and case studies.

Mechatronics concerns synergistic and concurrent use of mechanics, electronics, computer engineering, and intelligent control systems in modeling, analyzing, designing, developing, and implementing smart electromechanical products. As modern machinery and electromechanical devices are typically being controlled using analog and digital electronics and computers, the technologies of mechanical engineering in such systems can no longer be isolated from those of electronic and computer engineering. For example, in a robot system or a micro-machine, mechanical components are integrated with analog and digital electronic components to provide single functional units or products. Similarly, devices with embedded and integrated sensing, actuation, signal processing, and control have many practical advantages. In the framework of mechatronics, a unified approach is taken to integrate different types of components and functions, both mechanical and electrical, in modeling, analysis, design, and implementation with the objective of harmonious operation that meets a desired set of performance specifications.

In the mechatronic approach, a multidomain (mixed) system, consisting of subsystems that have a primarily mechanical (including fluid and thermal) or a primarily electrical (including electronic) character, is treated using integrated engineering concepts. In particular, electromechanical analogies, consistent energy transfer (e.g., kinetic, potential, thermal, fluid, electrostatic, and electromagnetic energies) through energy ports, and integrated design methodologies may be incorporated, resulting in benefits with regard to performance, efficiency, reliability, and cost.

Mechatronics has emerged as a bona fide field of practice, research, and development and simultaneously as an academic discipline in engineering. The present book is geared toward the focus on integrated research and practice as related to electromechanical and multidomain systems. In view of the analytical methods, practical considerations, design issues, and experimental techniques that are presented throughout the book, it serves as a useful reference tool and an extensive information source for engineers in industry and laboratories, researchers, and students in the field of mechatronics.

This book is an outgrowth of the Distinguished Visiting Fellowship of the Royal Academy of Engineering, UK, held by Clarence de Silva. The fellowship visit was organized by Farbod Khoshnoud. Through that fellowship, University of Hertfordshire and University of Oxford were visited, and among other activities, a workshop on mechatronics and applications was held. Many of the chapter authors of this book were speakers at that workshop.

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Editors

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200 technical papers and 6 monographs/textbooks. He received the first Fujian Province Youth Science and Technology Award.

Saman K. Halgamuge, PhD, is a professor in the Department of Mechanical Engineering and the school-wide initiative on biomedical engineering and associate dean (international) for the Melbourne School of Engineering, The University of Melbourne. He graduated with Dipl.-Ing and PhD degrees in electrical engineering from the Technical University of Darmstadt, Germany, and with a BSc in electronic and telecommunication engineering from the University of Moratuwa, Sri Lanka. His research interests are in big data analytics and optimization and in particular bioinspired methods focusing on applications in mechanical engineering and bioengineering. These applications vary from sensor networks in irrigation, smart grids, and sustainable energy generation to bioinformatics and neuro-engineering. Since arriving in Australia in 1996, Professor Halgamuge has obtained research grants totaling more than $8.3 million. These grants include funds worth $4.3 million from 17 Australian Research Council grants and a NHMRC project grant, local and European industry, contracts and grants from other research funding agencies and a large-scale ARC network, and infrastructure grants worth about $4 million. He has completed supervision of 27 PhD students and currently supervises a group of 13 PhD students. Professor Halgamuge is an associate editor of *BMC Bioinformatics* and founding co-editor of *Frontiers of Mechanical Engineering*, mechatronics section. He has published more than 250 research papers, including a research book, 5 edited books, 20 book chapters, 90 journal articles, and more than 130 refereed conference papers attracting 5200 Google Scholar (h-factor: 29) and 2300 ISI citations. He is listed among the top 1% most cited researchers by ISI's ESI. His full profile is found at http://scholar.google.com.au/citations?sortby=pubdate&hl=en&user=9cafqywAAAAJ&view_op=list_works.

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Mechatronic Engineering

Clarence W. de Silva

CONTENTS

SUMMARY This chapter introduces the subject of mechatronic engineering. It presents the relevance of modeling, design, and instrumentation in the development of a mechatronic system or product. The evolution of the discipline of mechatronics from its early days leading to the state of the art at present is outlined. Several application areas are given. The concepts of mechatronic design quotient (MDQ) and design evolution through modeling, health monitoring, design expert system, and evolutionary optimization are introduced.

1.1 Introduction

The subject of mechatronics concerns the synergistic application of mechanics, electronics, controls, and computer engineering in the development of electromechanical products and systems through an integrated design approach. Mechatronics is particularly applicable in mixed-domain (or multidomain) systems, which incorporate several physical domains, such as electrical, mechanical, fluid, and thermal, in an integrated manner. For example, the antilock braking system (ABS) of an automobile may involve mechanics, electronics, hydraulics, and heat transfer and may be designed in an "optimal" manner as a mechatronic product. Mechatronic products and systems include modern automobiles and aircraft, smart household appliances, medical robots, space vehicles, and office automation devices.

A typical mechatronic system consists of a mechanical skeleton, actuators, sensors, controllers, signal conditioning/modification devices, computer/digital hardware and software, interface devices, and power sources. Different types of sensing and information acquisition and transfer are involved among all these various types of components. For example, a servomotor, which is a motor with the capability of sensory feedback for accurate generation of complex motions, consists of mechanical, electrical, and electronic components. In a servomotor, the main mechanical components are the rotor, stator, bearings, mechanics of the speed sensor such as an optical encoder, and the motor housing. The electrical components include the circuitry for the field windings and rotor windings (not in the case of permanent-magnet rotors), and circuitry for power transmission and commutation (if needed). Electronic components include those needed for sensing (e.g., an optical encoder for displacement and speed sensing and/or tachometer for speed sensing). As another example, hard disk drives (HDD; see Figure 1.1) of computers use micro-miniature mechanical structures, actuators, and sensors for their operation and control.

The overall design of these devices can be improved by taking a mechatronic approach, with which all components and functions are treated concurrently in an integrated manner in their design. Furthermore, the study of mechatronic engineering should include all stages of modeling, design, development, integration, instrumentation, control, testing, operation, and maintenance of a mechatronic system.

Technology issues of a general mechatronic system are indicated in Figure 1.2. It is seen that they span the traditional fields of mechanical engineering, electrical and electronic engineering, control engineering, and computer engineering. Each aspect or issue within the system may take a multidomain character. For example, an actuator (e.g., DC servomotor) itself may represent a mechatronic device within a larger mechatronic system, such as an automobile or a robot.

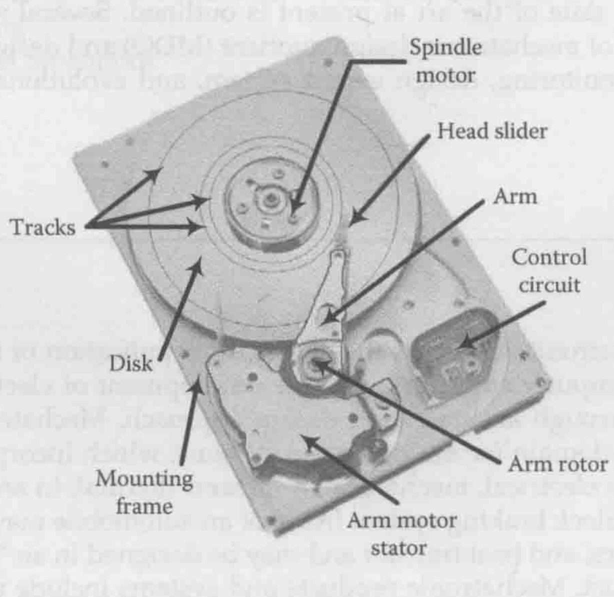

FIGURE 1.1
A HDD unit of a computer.

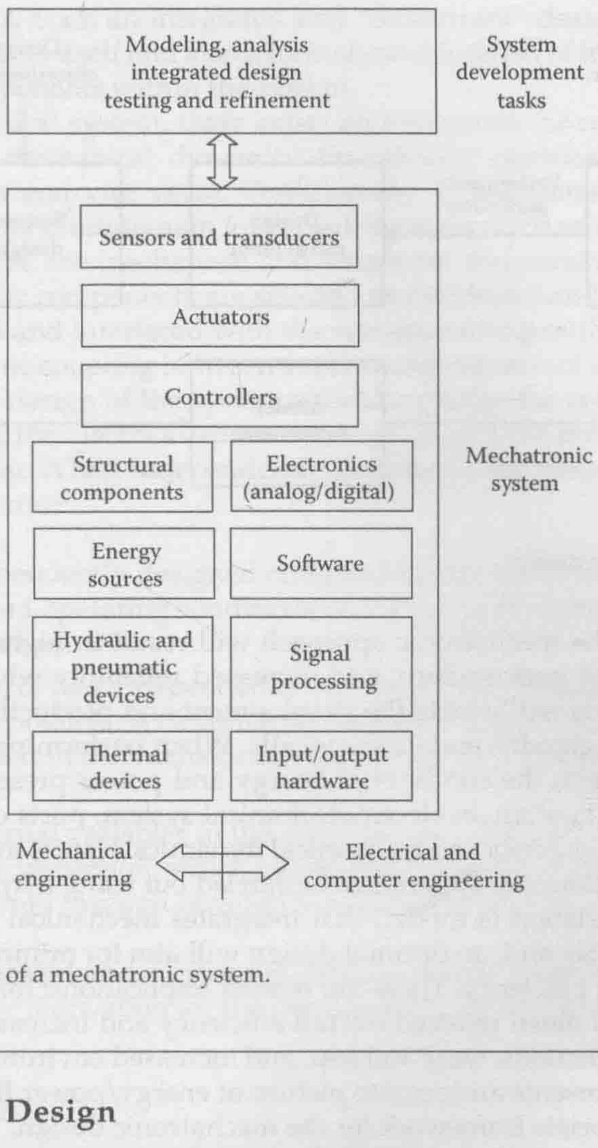

FIGURE 1.2
Concepts and technologies of a mechatronic system.

1.2 Modeling and Design

A model is a representation of a real system, and the subject of model development (modeling) is important in mechatronics [1,2]. Modeling and design can go hand in hand in an iterative manner. Of course, in the beginning of the design process, the desired system does not exist. In this context, a model of the anticipated system can be very useful. In view of the complexity of a design process, particularly when striving for an optimal design, it is useful to incorporate system modeling as a tool for design iteration particularly because prototyping can become very costly and time-consuming. Some details are found in Chapters 2, 3, and 9.

In the beginning, by knowing some information about the system (e.g., intended functions, performance specifications, past experience, and knowledge of related systems) and using the design objectives, it is possible to develop a model of sufficient (low to moderate) detail and complexity. By analyzing and carrying out computer simulations of the model, it will be possible to generate useful information that will guide the design process (e.g., generation of a conceptual design or preliminary design). In this manner, design decisions can be made, and the model can be refined using the available (improved) design. This iterative link between modeling and design is schematically shown in Figure 1.3.

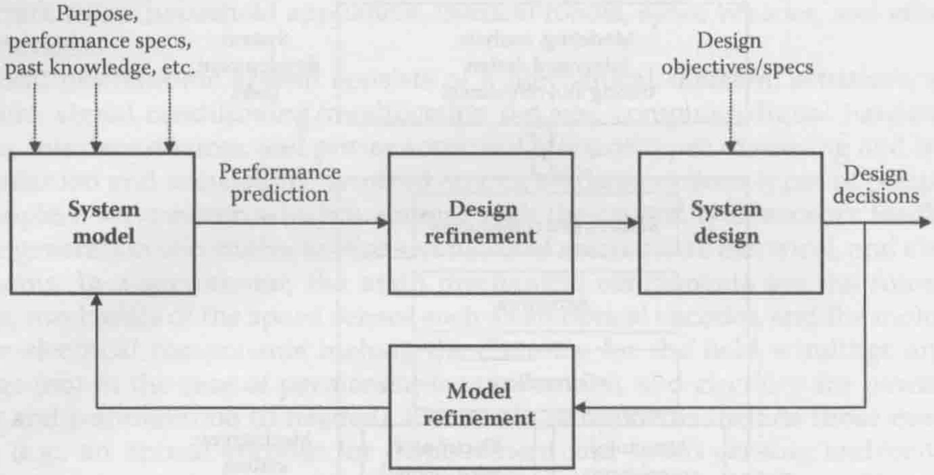

FIGURE 1.3
Link between modeling and design.

It is expected that the mechatronic approach will result in higher quality of products and services, improved performance, and increased reliability while approaching some form of optimality. This will enable the development and production of electromechanical systems efficiently, rapidly, and economically. When performing an integrated design of a mechatronic system, the concepts of energy and power present a unifying thread. The reasons are clear. First, in an electromechanical system, ports of power/energy exist, which link electrical dynamics and mechanical dynamics. Hence, modeling, analysis, and optimization of a mechatronic system can be carried out using a hybrid system (or multidomain system) formulation (a model) that integrates mechanical aspects and electrical aspects of the system. Second, an optimal design will aim for minimal energy dissipation and maximum energy efficiency. There are related implications; for example, greater dissipation of energy will mean reduced overall efficiency and increased thermal problems, noise, vibration, malfunctions, wear and tear, and increased environmental impact. Again, a hybrid model that presents an accurate picture of energy/power flow within the system will present an appropriate framework for the mechatronic design.

A design may use excessive safety factors and worst-case specifications (e.g., for mechanical loads and electrical loads). This will not provide an optimal design or may not lead to the most efficient performance. Design for optimal performance, however, may not necessarily lead to the most economical (least costly) design. When arriving at a truly optimal design, an objective function that takes into account all important factors (performance, quality, cost, speed, ease of operation, safety, environmental impact, etc.) has to be optimized. A complete design process should generate the necessary details for construction or assembly of the system.

1.3 Mechatronic Design Concept

In a true mechatronic sense, the design of a multidomain multicomponent system will require simultaneous consideration and integrated design of all its components as