# CHAPTER 1

# Introduction to Mechatronics

## 1.1 Introduction

Because of the large number of technological advances that have recently been made in a wide variety of multidisciplinary fields, the boundary between engineering sciences and the relative applications to which they can be applied has become blurred.

Modern devices are being used in advanced mechanical, electrical, and computer systems for industrial applications, and to assist in research. For instance, a modern textile machine utilizing electronics and sensory control systems performs more efficiently than a machine using complicated mechanisms. Another example is the modern automotive industry in which automobiles now integrate mechanical functions with electronic controls in order to provide more advantages such as higher performance and lower fuel consumption.

Mechatronics is a multidisciplinary engineering field, the combination of mechanical engineering, electrical engineering, and software engineering. In this chapter, mechatronic systems are discussed, including their design concept, framework, and importance in medical applications.

## 1.2 Mechatronic Systems

The Yasakawa Electric Company in Japan coined the word "mechatronics" in 1969. In the 1970s and 1980s, research and development activities made way for the growth and evolution of mechatronics. Yasakawa defined *mechatronics* in trademark application documents as follows:[1,2] "The word, mechatronics, is composed of 'mecha' from mechanism and the 'tronics' from electronics. That is to say technologies and developed products will now incorporate electronics more intimately and organically into mechanisms, making it impossible to tell where one ends and the other begins."

After Yasakawa suggested the original definition for mechatronics, some other definitions were also presented as follows:[3] In 1996, Harashima, Tomizuka, and Fukuda defined mechatronics as being "the synergistic integration of mechanical engineering, with electronics and intelligent computer control in the design and manufacturing of industrial products and processes."[4] In the same year, Auslander and

Kempf suggested another definition of mechatronics as being "the application of complex decision making to the operation of physical systems."[5] In 1997, Shetty and Kolk defined mechatronics as "a methodology used for the optimal design of electromechanical products."[6] In his recent book on mechatronics, Bolton presented yet another definition by saying "a mechatronic system is not just a marriage of electrical and mechanical systems and is more than just a control system; the mechatronic system is a complete integration of them all."[7] Although all the preceding definitions of mechatronics are correct and accurate, not one of them is fully definitive since the field of mechatronics is still in its infancy.[3]

Up to the early part of the twentieth century, mechanical systems were primarily used, and it was not until the 1920s that electrical drives were incorporated into mechanical systems. Since 1935, mechanical systems equipped with automatic control were devised, and in the 1950s electromechanical systems were developed as a result of progress in control engineering. In the 1960s, digital computers and information technology were developed with the advent of advances in the integrated circuit (IC) and microprocessor technologies. In the mid-1970s mechanical systems with digital control were developed and products or processes were integrated with electronics. It was not until 1980 that electromechanical systems, which had hitherto consisted of separate electrical and mechanical parts, were replaced by integrated electronic-mechanical systems containing sensors, actuators, and digital microelectronics culminating in the formation of the mechatronic system.

By definition, *synergy* is the ability of a group to outperform even its best individual member. It can be said about mechatronics, that through an integrated design approach this system does make synergistic use of mechanics, electronics, control theory, computer science, and information technology in the development of electromechanical systems and products. This means that mechatronics is a multidisciplinary engineering field which consists of mechanical engineering, electronics and electrical engineering, software engineering used in manufacturing, medicine, and the service industries. The main disciplines of mechatronics are shown in Fig. 1.1.

A typical mechatronic system consists of sensors, transducers, actuators, mechanisms, mechanical components, data acquisition devices, processing and control systems, software and expert system. The components of a mechatronic system are shown in Fig. 1.2.

Examples of mechatronic systems include, but are not limited to, space technology, transportation, optical telecommunications, automobiles, microwaves, automated manufacturing plants, wireless network enabled devices, micro electromechanical systems

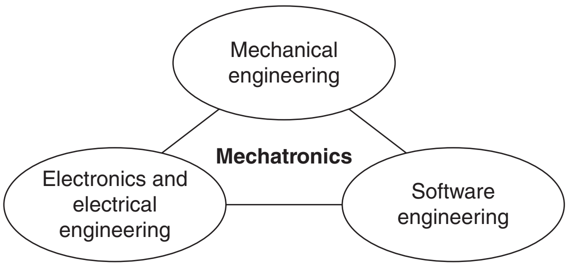


**FIGURE 1.1** The main disciplines of mechatronics as a multidisciplinary engineering field.

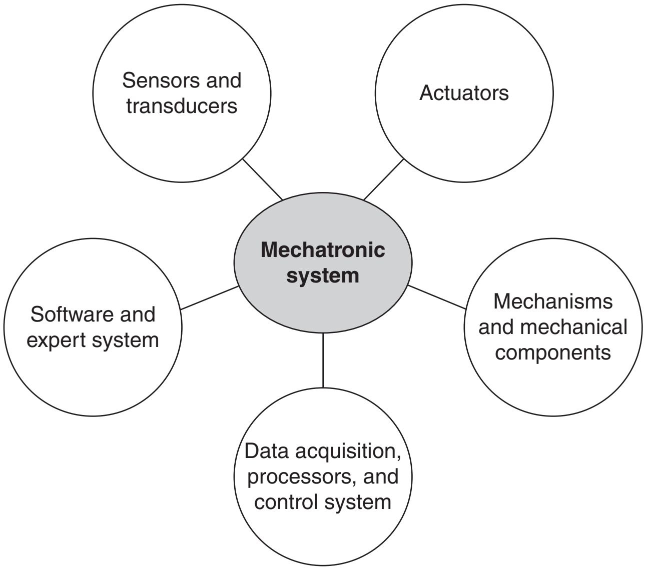


**FIGURE 1.2** Components of a mechatronic system.

(MEMS), automated diagnostic systems, biomedical devices, surgical devices, robots, and artificial organs.

The Japanese Society for the Promotion of Machine Industry (JSPMI), in the late 1970s, categorized mechatronic systems and products into four main classes as follows:[1]

> *Class I:* Primarily mechanical products incorporated with electronics to have enhanced functionality. Two examples of this are numerically controlled machine tools and variable speed drives in manufacturing machines.
>
> *Class II:* Classical mechanical systems with significantly updated internal devices including electronics but with an unchanged external user interface. Two examples are the modern sewing machine and automated manufacturing systems.
>
> *Class III:* Systems whose functionality is similar to the classical mechanical system, but their internal mechanisms are replaced by electronics. An example of this is the digital watch.
>
> *Class IV:* Products designed with synergistic integration of mechanical and electronic technologies. Examples are photocopiers, intelligent washers and dryers, and automatic ovens.

The above mechatronics product classes are based on development in various technologies. Class I products were generated by using servo technology, power electronics, and control theory. Class II products were generated by using early computational and memory devices and custom circuit design capabilities. Class III products were based on the microprocessor and integrated circuits to replace mechanical systems, and Class IV products relied on the beginning of true mechatronic systems which were the combination of mechanical systems and electronics.[3]

In the classical development of an electromechanical system, the mechanical and electrical components are first designed or selected separately and then integrated with other hardware and software components. However, in the mechatronics approach, the whole electromechanical system is designed simultaneously in an integrated manner by a multidisciplinary team of professionals.

A system produced by interconnecting a set of separately designed and constructed components will not provide the same level of performance as a mechatronic system that employs an integrated approach for design, development, and execution. The main reason is that the best operation can only be achieved through an integrated approach to design, development, and execution by ensuring that optimum compatibility exists between each discrete entity in the system.

In general, a mechatronics product is more efficient, cost effective, compact, accurate, reliable, flexible and practical, and mechanically simpler than an alternative product.[8] Although by using a complex control system the performance of such an alternative system can be improved, it would require the additional cost of sensors, instrumentation, control hardware and software.[8]

## 1.3 Mechatronics Design Concept and Framework

Mechatronics design is a combination of physical modeling systems and simulation techniques. It is used to design complex machines by combining mechanical and physical characteristics with electronics and software to achieve a real-time prototype. In designing a mechatronic system, various factors such as quality, performance, cost, safety, speed, etc., must be considered and optimized.

One example of mechatronic systems is robot manipulation. The robotics industry came to the fore in the late 1970s and early 1980s due to the increasing availability of low-cost digital signal processors (DSPs) and microprocessors that possessed high-computational power. Robotic manipulators are used in many applications, such as manufacturing processes and robotic assisted surgery. A robotic manipulator has four major subsystems, and every modern mechatronic system has the same subsystem functionalities:[9]

1. A mechanism to transfer motion from an actuator to the instrument.
2. An actuator (a motor and power amplifier, a hydraulic cylinder and valve) and power source (DC power supply, internal combustion engine and pump).
3. Sensors to measure the motion variables.
4. A controller (data acquisition, microcontroller, microprocessor and DSPs) together with operator user interface devices and communication capabilities to other intelligent devices.

Because a mechatronic system usually consists of various types of interconnected components and elements, there is energy conversion from one form to another, especially between electrical energy and mechanical energy. In an electromechanical system, there is an interaction or coupling between the electrical dynamics and the mechanical dynamics in which each have an effect on the other. The dynamic coupling between various components of a system shows that it is more prudent to design the system as a whole rather than designing the electrical parts and the mechanical parts separately.

The following problems can occur when independently designed components are interconnected:[8]

1. The original characteristics and operating conditions of the components tend to change as a result of loading or dynamic interactions.
2. Perfect compatibility of two independently designed components will be practically impossible and a component is likely to become either underutilized or overloaded.
3. Some of the external variables in the components will become internal and hidden as a result of interconnection, which causes potential problems that cannot be explicitly monitored through sensing and, therefore, cannot be directly controlled.

The limitations inherent within most classical mechanical-electronic systems include: the lack of appropriate sensors and actuators, inadequate lifetime under rough operating conditions (acceleration, temperature, and contamination), large space requirements, bulky cabling, and relatively slow data processing.[3] In the design of a mechatronic system, however, with the advent of miniaturization, robustness, and computing power of microelectronic components, electronics can be improved and more autonomous systems can be visualized, such as capsuled units with touchless signal transfer or bus connections, and robust microelectronics.[3]

There are two types of integrations in a mechatronic system: the integration of components (hardware integration) and the integration of information processing (software integration).[3]

Hardware integration results from designing the mechatronic system as an overall system and inserting sensors, actuators, and microcomputers into the mechanical system. Integrated sensors and microcomputers form smart sensors, and integrated actuators and microcomputers form smart actuators. For larger systems, bus connections will replace cables and so there are several possibilities to generate an integrated overall system by proper integration of the hardware.[3] Software integration, or the integration of information processing, is generally based on advanced control functions. Besides a basic control, an additional influence may be caused by processing available signals at higher levels, including the solution of tasks such as fault diagnosis, optimization, and general process management. Therefore, a knowledge base that comprises methods for design and information gathering, process models, and performance criteria is required.[3]

## 1.4 Importance of Mechatronics in Medical Applications

Due to the high sensitivity of medical equipment, for which the hygienic aspect must be considered, rapid developments in facilitating and observing high standards of hygiene and treatment are always observed. These developments naturally require different specialties in order to design accurate, intelligent, and efficient systems. Medical instruments were always designed to fulfill a specific function and, in the right hands, were invariably used to good purpose. Introduction of modern devices and fields such as the artificial heart, robotic surgery, and intelligent probes shows that the efficiency of conventional tools depends as much on the appropriate combination of mechanics, electronics, and computer science as it does on the skilful use to which they are subsequently put. For instance, within the field of medicine, telerobotics is a complicated mechatronic system that can be used in minimally invasive surgeries to perform surgical procedures with a very high degree of precision. The design and development of telerobotic systems, therefore, plays an important role in improving the quality of surgical procedures and reducing potential problems. Using mechatronic systems, researchers are also investigating implantation techniques in the human body, using micro- and nanotechnology to repair or replace damaged physiological functions.

This book introduces and discusses modern solutions for utilizing mechatronics in designing these novel methods and optimizing conventional medical instruments. Because mechatronics fosters new concepts and development in an ever-increasing number of fields and disciplines, new devices will always be introduced, and advances made, that will spearhead and encourage further research. If this is so, mechatronics will surely have a bright and highly influential future.

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