Chapter 2

Mechatronics Education

New technology and products necessitate the teaching of mechatronics either as a separate discipline or as part of mechanical engineering. However, there are a lot of differences in perceiving the meaning, scope and objective of mechatronics. In this chapter, the concept of mechatronics is explained with reference to its historical development and its application in developing mechatronic products. A review on mechatronics education is presented. A discussion about how mechatronics education can be imparted is provided. Sample course structure has also been included. Some examples of mechatronics projects are presented. The chapter concludes with a discussion about challenges in mechatronics education and possible measures to overcome these challenges.

2.1. Introduction

Although engineering is as old as civilization, formal education in engineering started to gain popularity from the beginning of the 19th Century. In the beginning, engineering

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consisted of two distinct disciplines – military engineering and civil engineering. Military engineering was concerned with the design, development, manufacture and maintenance of war-related infrastructure. Civil engineering was concerned with the engineering of all non-military applications. The spread of the Industrial Revolution and developments in the transportation sector provided impetus to the emergence of a new discipline of mechanical engineering. Research in the development of the electrical motor gained momentum from the beginning of 19th Century, but practical application only started in the last quarter of the century. The discipline of electrical engineering developed to cater to the specific need of power generation and motors. Later on, disciplines like electronics, instrumentation and computer science emerged from electrical engineering. Similarly, production engineering, industrial engineering, chemical engineering, metallurgical engineering and so on inherit a number of features from mechanical engineering. As engineering is an applied science and art, the employability of graduates affects the creation of the discipline to a great extent. Thus, market needs put the pressure on academics to modify the existing engineering program or create a new one. This is true in the case of mechatronics, which emerged as a discipline due to requirement of engineers for designing, operating, manufacturing and maintaining a number of products needing a synergistic involvement of more than one discipline for their development. Some examples of such products are robots, computer numerical control (CNC) machine tools, photocopiers and modern aircrafts.

The term mechatronics was first coined by a Japanese engineer named Tetsuro Mori of the Yaskawa Electric Corporation. The trademark rights for the term "Mechatronics" were granted to Yaskawa in 1971. Yaskawa elected to abandon its rights on the word in 1982. Now mechatronics is understood as the synergistic combination of mechanical engineering, electrical engineering, electronics, control engineering, system design engineering and computer engineering to create and maintain useful products.

Mechatronics entered the academic sector in two distinct forms – as a course and as an engineering discipline. This chapter discusses various aspects of mechatronics education including the difficulties and challenges.

2.2. A brief history of mechatronics

The word mechatronics is a combination of the words – mechanical and electronics, and these two disciplines have major influences on the development of mechatronics. It will be appropriate to discuss a brief history of mechanical and electronics engineering before understanding the growth of mechatronics. Accordingly, this chapter is divided into three subsections covering the history of mechanical engineering, electronics and mechatronics. The information presented in this section is scattered over several places, but a good reference is [GAR 98].

2.2.1. *History of mechanical engineering*

The history of mechanical engineering is very old. In the Hellenistic period (323–146 BC), Greek civilization was at its zenith. The Greek mechanical engineer or *mechanomai* used to apply the principles of science and art in various mechanical gadgets. Archimedes (287–212 BC) was a leading scientist and engineer from that period. He explained the principle of lever and designed a number of innovative machines including the screw pump. The screw pump called Archimedean screw was used to pump water.

Machinery in antiquity was either powered by man or water. Water mills were used to grind corn and drive powerful forging hammers and bellows for metallurgy. In some places, mining hoists were driven by water wheels. The cogwheel and gear wheels evolved with water wheel technology. A 5th Century BC poem mentions a water wheel. Heron of Alexandria (AD 10–70) describes a wind organ with a piston providing air for the organ pipes. The organ piston is moved by rotating a wheel. Thus, the slider crank mechanism was known at that time. Heron described the construction of *aeolipile*, a rocket-like reaction engine and the first recorded steam engine. The first vending machine was also his construction. When a coin was inserted into a slot on the top of machine, a fixed amount of holy water was dispensed. Heron authored a book on mechanics and optics.

Philon of Byzantium (280–220 BC) discusses catapult design in his book Compendium of Mechanics. Termed as either a dart thrower or stone throwers, they evolved as a class of machines from the 4th Century BC to remain as a mainstay of armies, until the invention of gun powder. Philon has also described pneumatic machines.

Ships are an example of wood and water technology. Oared ships were favored as warships by the Egyptians during the reign of Ramses III (1198–1166 BC). Archimedes designed a huge galley named the *Syrakosia*. The vessel was the first three-mast ship in the world.

In the medieval period, scholasticism (1100–1500 AD) aimed at the reconciliation of faith and reason. It unwittingly promoted the development of mathematics and science. During the medieval period, a lot of developments were made in civil engineering, metallurgy and basic sciences. Indian smiths had developed the wootz process for developing steel. This technology first appeared in the first millennium AD. We do not see much development in mechanical engineering during this period. Most of the machines were driven by animal power or water. Windmills were also prevalent during this period.

The development of science and technology suffered as a result of the Hundred Years War (1337–1453) in France and the bubonic plague. This pandemic is known in history as *Black Death*, which was at its peak in Europe, from 1348 to 1350. It killed one-third of the population of Western Europe, particularly in England, France, Spain and Germany. The rebirth of science and technology took place during the Renaissance, a cultural movement that spanned roughly from the 14th to the 17th Century. In the early period of the Renaissance, science and art were intermingled, the example being the works of Leonardo da Vinci. Leonardo da Vinci systematically studied aerodynamics. He is called the “father of modern science” by some historians.

Among the physical and mechanical problems examined by Renaissance scientists, two were of fundamental importance to mechanical engineering: (1) the composition of forces and the law of force parallelogram and (2) the problem of bending of a beam. Galileo Galilei (1564–1642) was an Italian physicist who contributed a lot to the science of mechanical engineering. Galileo has designed and fabricated a number of instruments, for example the thermometer that utilized the principle of the expansion of air. He also designed an escapement mechanism for a pendulum clock. This mechanism converts the rotational motion of a gear into an oscillating motion. Sir Isaac Newton (1642–1727) published *Philosophiae Naturalis Principia Mathematica* in 1687. In his book, Newton described universal gravitation and the three laws of motion.

The ancient philosophers and men of science in Persia and Greece proposed four basic elements of the universe, i.e. earth, air, fire and water. In the Indian tradition, in addition to these, space is also considered a basic element. Of these, air and water were used as prime movers. However, it was only in the 17th and 18th Centuries that the use of heat as a source of power was explored. On 2 July 1698, Thomas Savery (1650–1715), a military engineer, patented an early steam engine for the raising of water. He demonstrated it to the Royal Society on 14 June 1699. He first used the term "horsepower". Thomas Newcomen (1664–1729) developed a steam engine around 1710. James Watt modified Newcomen's engine. Watt's engine used 75% less coal than Newcomen's. Newcomen's and Watt's early engines were powered by the vacuum generated by condensing steam instead of the pressure of the expanding steam. Watt invented the steam condenser, parallel motion gearing, double action engines and the centrifugal governor.

Originally, engineering had only a military meaning. In 18th-Century Europe, the meaning was expanded and given a civil application like in the building of canals and bridges. John Smeaton (1724–1792) is often regarded as the father of civil engineering. He also employed his skills in mechanical engineering. He developed the water engine and water mill. He also improved Newcomen's steam engine. With the advent of steam, mechanical engineering started flourishing.

Nicolas Leonard Sadi Carnot (1796–1832), the French military engineer, is called the "father of thermodynamics". At the age of 28, he published his seminal work *Reflexions sur la Puissance Motrice de Fe* (*Reflections on the Motive Power of Heat*). He suggested one ideal thermodynamic cycle called the Carnot cycle. An engine operating between two temperatures will have the highest thermal efficiency, if it works on the Carnot cycle. Even though Carnot died of cholera at the age of 36 in 1832, because of his contribution, he is often considered the "father of thermodynamics".

The German theoretical physicist, Rudolf Julius Emmanuel Clausius (1822–1888), and the French civil engineer, Benoit Pierre Emile Clapreyron (1799–1864), jointly provided the Clausius–Clapreyron equation. Around the same time James Prescott Joule (1818–1889) discovered the equivalence of heat and mechanical work. The work of these three scientists resulted in the formulation of the first and second law of thermodynamics.

Nikolaus August Otto (1832–1891) produced a small four-stroke internal combustion (IC) engine in 1861. Alphonse Beau de Rochas took out a patent in 1862, describing only the main details of a four-stroke cycle. He did not provide any suggestions on how it might be used. Therefore, it is believed that Otto independently invented the same cycle.

Jean Étienne Lenoir (1822–1900) took out a patent on IC engines two years before Beau de Rochas in 1860. He used illuminating gas for his engine and by 1865 produced over 300 engines ranging from 1/3 to 3 horsepower. These engines were four-cycle, low in compression and inefficient. Illuminating gas, also known as town gas, contains hydrogen, methane and carbon monoxide. Lenoir put one engine on a carriage and created a motor car. Later he installed one engine in a boat.

Otto also described a working two-cycle engine, but this was invented by Sir Dugald Clerk, born in Glasgow, Scotland in 1854. The early engines had the rotational speed of about 200 rpm. Gottlieb Daimler (1834–1899) developed engines working at about 1,000 rpm. In 1892, Rudolf Diesel (1858–1913) developed a diesel engine using compression ignition.

The first steam-powered automobile was developed in 1769. An IC engine working on a gas mixture was developed in 1806 for use in automobiles. In 1826, Samual Brown tested his hydrogen-fueled IC engine by building it to propel a vehicle. In 1870, an Austrian inventor S. Marcus placed a liquid-fueled IC engine on a simple handcart, which was the first vehicle run by gasoline. Practical automobiles running on petrol or gasoline were developed around 1885. In 1838, Robert Davidson had built an electric locomotive that attained a speed of 6 km/h.

These technological developments helped the industrial revolution during the rapid industrial development in the late 18th and early 19th Centuries. It started with the mechanization of the textile industries, the development of iron-making techniques and increased use of refined coal. The development of machine tools in the first two decades of 19th Century helped to produce more machines. The second industrial revolution started in 1850 with the development of steam-powered ships and railways. The developments of IC engines and electric power generation boosted the industrial development. John Stevens (1749–1838), called the "father of American railroads", developed the first machine shop delivering mass production in 1804.

Early mechanical engineers used the principles of physics to invent, design and develop the machines. Frederick Winslow Taylor (1856–1915) introduced management into mechanical engineering. He was a mechanical engineer and was interested in improving the efficiency of production. He is called the "father of scientific management". He also researched into machining. He developed an empirical relation between cutting speed and tool life. F.W. Taylor is often known as the father of industrial engineering. In the United States, Henry R. Tone was a pioneer in developing the industrial engineering field. He was a member of ASME. In 1948, a new society, the American Institute for Industrial Engineers, was founded. Table 2.1 shows some landmark events in the history of mechanical engineering.

2.2.2. *History of electronics engineering*

Electronics was born from electrical engineering, which in turn accelerated the development of computer hardware. The history of electronics will include a portion on the histories of electrical engineering and computer science. The history of electrical engineering can be considered from the beginning of 19th Century. The concept of the direct current (DC) was discovered by Michael Faraday (1791–1867) who deduced the principle of the generator and transformer. William Sturgeon (1783–1850), an English physicist, invented the first practical electric motor. Thomas Davenport (1802–1851), an American blacksmith, patented an electric motor in 1837, which was used to power machine tools and printing presses. Due to the high cost of primary battery power, the motors were commercially unsuccessful and Davenport became bankrupt. In those days, electricity distribution was unavailable. The modern day motor was invented accidentally by Zenobe Gramme, when he found that the dynamo invented by him was reversible. In 1888, Nicola Tesla invented the first AC motor. The application of electric motors revolutionized industry, as the power transmission losses were minimized.

Although the history of electronics starts with the development of the vacuum tube in 1883, it grew rapidly after the invention of the transistor by John Bardeen, Walter Brattain and William Shockley in 1947. In acknowledgment of this accomplishment, Shockley, Bardeen and Brattain were jointly awarded the 1956 Nobel Prize in Physics for their research on semiconductors and the discovery of the transistor effect. The concept of the integrated circuit was proposed by Geoffrey W.A. Dummer in 1952. In 1958, Texas introduced the first commercial integrated circuit. The first handheld calculator was developed in 1967. In 1968, Burroughs produced the first computer to use an integrated circuit.

Starting from the early part of the 1970s, a number of mechanical products started using microprocessors. In 1971, Intel® produced the first commercial microprocessor 4004. It uses 2,300 transistors and has a clock speed of 108 kHz. In 1980, Intel® introduced the first 32-bit microprocessor. In 1981, IBM introduced a personal computer with an industry standard disk operating system (DOS). In 1990, the World

Wide Web (WWW) was set up by Tim Berners-Lee at the European Particle Physics Laboratory in Switzerland. In 1993, Intel® introduced the Pentium® processor. In 2000, Intel® introduced Pentium® 4, which uses about 42 million transistors and has a clock speed of 1.4 GHz. In 2006, Intel® introduced the Core 2 processor.

Event	Year
The first steam engine (used as a water pump) by Thomas Savery	1698
Steam engine installed by Thomas Newcomen	1712
The first tandem rolling mill patented by Richard Ford	1766
The first commercial steam engine based on James Watt's design	1769
Richard Trevithick developed a high-pressure engine	1799
The first car powered by an IC engine running on fuel gas	1806
George Stephenson (1781–1848), the father of railways, designed his first locomotive	1814
Samuel Brown patented first the IC engine to be applied industrially	1823
Nikolaus Otto developed a practical four-stoke cycle IC engine	1876
Karl Benz got a patent for a two-stroke IC engine	1879
James Atkinson developed the Atkinson cycle engine	1882
Herman Hollerith invented an electro-mechanical machine to tabulate information using cards with punched holes	1890
Rudolf Diesel demonstrated the diesel engine using a peanut oil fuel (bio-diesel)	1900
The first working gas turbine by Aegidus Elling (1861–1949), the father of the gas turbine	1903
Wright brothers applied for patents for their flying machine in Germany and France	1904
The first successful military plane	1909
Boeing's first passenger aircraft	1928
The first NC machine at MIT	1952
The first CNC machine at MIT	1957

Table 2.1. *Some landmark events of mechanical engineering*

2.2.3. *Growth of mechatronics*

The term mechatronics was coined in 1969, but the advent of mechatronics can be traced back to the early 1950s. A prototype numerical control machine tool was demonstrated at the Massachusetts Institute of Technology (MIT) in the United States. It was a retrofitted milling machine. In 1957, the first CNC machine was developed at MIT. In 1961, the part programming language Automatically Programmed Tooling (APT) was released for automatic machining of the components on CNC machines. The operation and maintenance of CNC machines required an engineer to be skilled in mechanical engineering, electronics and programming. Thus, the need for a new discipline was felt.

Development of robotics is also linked with the growth of mechatronics. In 1959, the Planet Corporation introduced the first commercial robot based on limit switches and cams. In 1961, a Unimate robot was installed by Ford to service a die-casting machine. In 1978, a Programmable Universal Machine for Assembly (PUMA) robot was introduced by Unimation. The PUMA robot had six degrees of freedom with revolute joints that were operated by DC servo motors. In 1979, the Selective Compliance Arm for Robotic Assembly (SCARA) was developed by Yamanshi University in Japan. A SCARA robot has all its axes for revolute joints along a vertical direction. This makes the SCARA robot rigid along z-direction and compliant along x–y-direction. That is why it is called a selective compliance arm. In 1998, Honda introduced the P3 humanoid robot. In 1999, Sony introduced the AIBO robot dog. AIBO is acronym for Artificial Intelligence Robot. In 2000, Honda introduced ASIMO a humanoid robot. ASIMO is an acronym for Advanced Step in Innovative MObility. In 2007, TOMY, USA, introduced the i-SOBOT humanoid robot. The robot i-SOBOT is endowed with 17 custom developed servo motors, 19 integrated circuit chips, a built-in gyrosensor, two light emitting diodes, voice command recognition and can speak and perform hundreds of words, phrases and preprogrammed actions, over 90 kinds of sound effects and can play five songs.

In 1971 and 1978, the Japanese Ministry of International Trade and Industry (MITI) passed legislation that encouraged joint research between the machinery and electronics industries. By 1990, mechatronics had established itself as an important field of engineering and the *Mechatronics* journal was launched in the United Kingdom by Pergamon Press. This journal covers technical innovations in the field of mechatronics. In 1996, IEEE–ASME launched the *Transactions on Mechatronics* journal.

Mechatronics is evolving as the technological developments are taking place in various areas. Tomozuka (2002) has pictorially depicted the evolution of mechatronics from 1970 to 2000 in Figure 2.1, which shows that electronics and control theory were major players in mechatronics at the beginning. At present embedded systems, information technology (IT) and decision making has an important role.

2.3. Definitions and scope of mechatronics

Mechatronics has been defined in a number of ways. Various definitions can be found in research papers, books, university brochures and industry catalogs. It is difficult to trace the original author of the definitions and this will not be attempted here. The main aim of this section is to critically analyze the definitions to understand mechatronics more clearly. Some definitions are as follows:

DEFINITION 2.1.– *Mechatronics systems are the systems dealing with the movement of mass, electrons and information.*

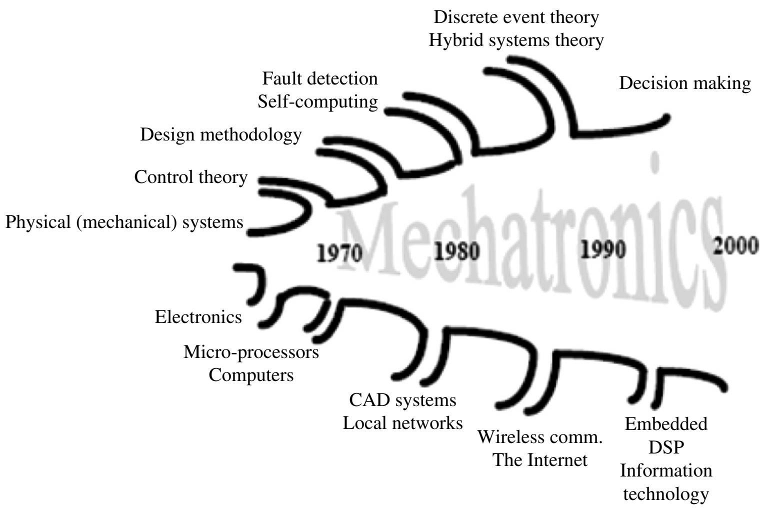


Figure 2.1. *Evolution of mechatronics. With permission from [TOM 02]© 2002 Elsevier*

This definition on the one hand is too general and on the other hand excludes many products, where there is no movement of mass. For example, an electric rice cooker can be considered a consumer mechatronic product, although there is no movement of mass in it. Moreover, this definition does not explicitly talk about the integration of different disciplines.

DEFINITION 2.2.– *Mechatronics is the ability to integrate electronics and computing technologies into a wide range of primarily mechanical products and processes.*

This definition talks about the integration of different disciplines. However, it restricts the scope of mechatronics by restricting it to mechanical products and processes. With this definition a CD-writer may not be called a Mechatronic product. Although this product is a part of computer hardware, it involves integration of mechanical engineering, electrical devices and electronics.

DEFINITION 2.3.– *Mechatronics is the synergistic integration of mechanical engineering with electronics and intelligent computer control in the design of products and processes.*

In this definition, an important term is “synergistic”; the dictionary meaning of which is “of and relating to synergy”. One meaning of “synergy” is “the interaction of two or more agents or forces so that their combined effect is greater than the sum of their individual effects”. Thus, the definition brings out the power of mechatronics, which is much more than the sum of the powers of different disciplines. However, the definition restricts mechatronics to the domain of design. Actually, mechatronics find applications in manufacturing and maintenance as well.

DEFINITION 2.4.– *Mechatronics is the application of methodology, techniques and understanding of one or more disciplines to another discipline.*

This definition is sufficiently general to encompass all types of present and future products. It is possible that future products may have enough portions of biotechnology or other related areas. Thus, there have to be engineers who can understand different disciplines. However, this definition misses the important aspect of “synergy”.

DEFINITION 2.5.– *Mechatronics is the synergistic combination of precision engineering, electronic control technology and systems thinking in the design of product and processes.*

This definition was provided by the European Union-sponsored Industrial Research and Development Advisory Committee working group in the late 1980s. This definition restricts mechatronics to the domain of design.

DEFINITION 2.6.– *Mechatronics is the application of complex decision making to the operation of physical systems.*

This definition overemphasizes the decision-making process. There can be mechatronic products involving the integration of different disciplines without having a decision-making capability in the product.

DEFINITION 2.7.– *Mechatronics is the synergetic integration of physical systems with information technology (IT) and complex-decision making in the design, manufacture and operation of industrial products and processes.*

This definition rightly expands the scope of mechatronics to design, manufacture and operation. It also includes the important word “synergetic”. The definition stresses IT and complex decision making, but misses the mention of mechanics and electronics.

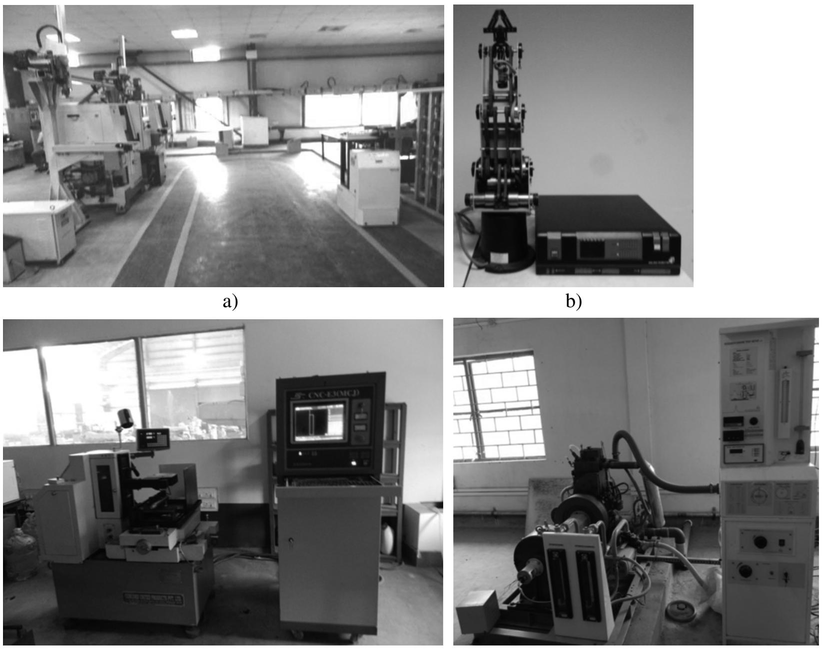
Based on these definitions and considering the present day scope of mechatronics, the following definition is proposed:

Mechatronics is the synergetic integration of mechanical engineering, with electrical engineering and/or electronics, and possibly, with other disciplines, for the purposes of design, manufacture, operation and maintenance of a product.

This definition channels the scope of mechatronics to products having sufficient content of mechanical and electrical or electronics discipline. At the same time, it accepts the scope of other disciplines. Moreover, it brings out the applicability of mechatronics for design, manufacture, operations and maintenance.

2.4. Examples of mechatronic products

We can provide a number of examples of mechatronic products. Computer numerically controlled (CNC) machines, robots, material handling systems and flexible manufacturing systems (FMS) are a few examples of mechatronic products in manufacturing. In automobiles, the antilock mechanism of four-wheelers, the electronic ignition system, the engine control system and so on are all examples. In consumer products, cameras, washing machines, toasters, photocopiers are mechatronic products. In civil engineering, smart structures fall into the category of mechatronic products. Figure 2.2 shows some mechatronic products used in industry.



a) b) c) d)

Figure 2.2. *Some examples of mechatronic products: a) a flexible manufacturing system, b) a robot, c) a wire-cut electro-discharge machine and d) an engine testing rig*

There are generally two types of mechatronic products. In one type of product, electronics, electrical equipment or computers have enhanced the capabilities of a mechatronic product, but the basic structure remains the same. Examples are CNC machines. In other type of product, electronics have totally replaced mechanical functions. An example, is the electronic watch.

Several examples can be cited, where mechatronics have been applied to enhance the quality of the product. CNC machines can produce accurate and complex shapes compared to their traditional counter parts. IC engines can be equipped with electronic control. Many consumer products such as washing machines, refrigerators and air-conditioning systems have been made more efficient and attractive by integrating electronics within them. These products can be called mechatronic products.

There are several products that have been totally replaced by electronics. For example, a digital electronic watch does not have moving parts like its mechanical counterparts. Similarly, with the development of electronics, the speed of motors can be controlled efficiently, removing the use of belt, chain and gear drives. Electronic cams can be used in place of traditional cams. In electronic cams, the follower is a nut, which can be moved up and down by a ball screw. The rotation of a ball screw can be controlled by a stepper motor.

It is worth mentioning that of late there has been a trend of replacing all mechanical elements with electronics. This tendency should be avoided. Instead the best solution must be searched. For example, sometimes putting a mechanical indicator may be more cost-effective and reliable than an electronic indicator.

2.5. Review of literature in the area of mechatronics education

Education in mechatronics has started gaining popularity starting from early 1990s. A number of papers have been published in the area of mechatronics education. Some papers are briefly summarized.

Fraser *et al.* [FRA 93] have described how mechatronics can be taught within the traditional curriculum by illustrating the mechatronics teaching practice at Dundee Institute of Technology in the United Kingdom. The authors have suggested including the following topics in the mechanical engineering curriculum: (1) systems design, (2) microprocessor technology, (3) digital electronics, (4) digital and analog interfacing techniques, (5) digital communications, (6) software development, (7) sequential control of electrical, pneumatic and hydraulic systems and (8) control principles. The authors have described two examples of mechatronic products:

1) Design of a diameter measurement device for a harvesting head: a harvesting head is a mechanical or hydraulic attachment to a vehicle that fells and prepares trees to a condition suitable for carrying to sawmills. The objective of the project was to design a system for measuring the diameter of trees. The designed system is shown in Figure 2.3.

2) Automation of the handle attachment process for woven polymer sacks: a local company was facing a problem in attaching handles to the woven polymer sacks due to worker absenteeism. It was decided to automate the system. A pneumatically operated system controlled by a programmable logic controller (PLC) was designed. It was tested on shop floor conditions.

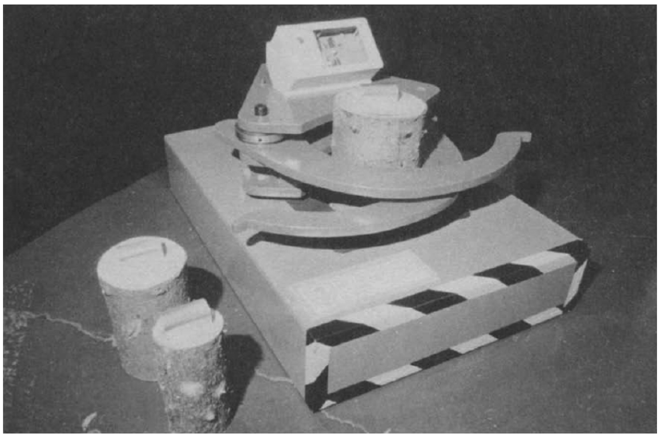


Figure 2.3. *Diameter measuring device for a harvesting head. With permission from [FRA 93]© 1993 Elsevier*

Hanson [HAN 94] discussed the teaching of mechatronics at the master's level, with reference to teaching at the Royal Institute of Technology, KTH in Sweden. The author has concluded that a project-oriented approach is beneficial in the teaching of mechatronics. He has discussed the application of mechatronics to the area of biomechanics. In the introduction, the author has provided an interesting history of mechatronics education at KTH. In the middle of the 1970s, digital electronics, microcomputer architecture, assembler programming and input or output interfacing were introduced in the curricula of mechanical engineering. Mechatronics was understood as "microcomputers in mechanical systems". In the beginning of 1980s, the focus was on embedded real-time control systems, and the expression "computer controlled mechanics" was used for mechatronics. In the 1990s, mechatronics was defined as mechanical devices and systems programmed or programmable with perception, action and communication. Systems of all sizes starting from nanotechnology to gigantic heavy industrial systems were included.

Acar and Parkin [ACA 96] have reviewed various aspects of mechatronics education. According to authors, mechatronics is not a new branch of engineering, but a newly developed concept that underlines the necessity for integration and intensive interaction between different branches of engineering. “Mecha” in mechatronics should be understood as the widest aspect of the physical embodiments of mechanical engineering, including optical elements, while “tronic” should be understood to embrace all aspects of microelectronics and IT including control. Authors also emphasize that many courses in mechatronics are simply gluing mechanical and electronics topics and lack a coherent integrative theme. Generalist and specialist approaches of education are compared. The Japanese approach to product developmental strategies and mechatronics education and training is discussed. The authors argue that the success of Japanese industry in designing, developing and marketing mechatronic products and system may be attributed to the Japanese approach to product developmental strategies, their education and their training system. The authors have emphasized the need for the involvement of industries in education.

Tan *et al.* [TAN 98] have discussed various developments in mechatronics in Asia from three perspectives: education, research and application of technology. The education scenario in the following countries was discussed in detail: Japan, Korea, Singapore, China, Taiwan and Hong Kong. The developments in Thailand and Indonesia were also briefly discussed. Many Asian countries offer degree or diploma programs in mechatronics. In almost all countries under the survey, the government has been the main support. Collaborative research with industry has been actively developed. A lot of interest is also being shown in microelectronics.

Lyshevski [LYS 02] has reviewed mechatronics education. The author has discussed the curriculum, software and books in mechatronics. The author has emphasized the need to include projects into the mechatronics curriculum. According to him, the mechatronics curriculum can be viewed as the vehicle by which students are introduced to the subject matter, multidisciplinary areas and disciplines. The author classified the mechatronics system as conventional mechatronic systems, microelectromechanical–micromechatronic systems (MEMS) and nanoelectromechanical–nanomechatronic systems (NEMS). The author points out that the theory governing the behavior of conventional and MEMS mechatronic systems are the same, but NEMS are governed by different theories including quantum theory.

Tomizuka [TOM 02] has presented a Y2K status report for mechatronics. He defined mechatronics as the synergetic integration of physical systems with IT and complex decision-making in the design, manufacture and operation of industrial products and processes. IT in the context of mechatronics includes computers and digital signal processors and the Internet. The ASME has identified the following eight areas to impact on mechanical engineering in a major way:

1) Information technology

2) Miniaturization

3) Materials science

4) Bioengineering and medicines

5) Energy

6) Transportation

7) Environmental engineering

8) Manufacturing.

In the last five areas, the visible mechatronics activities have already taken place, whereas, the first three activities are the enabling technologies. Mechatronics can also be used to take care of elderly people, which can be called human friendly mechatronics. The author has also discussed the research opportunities in mechatronics. Three mechatronics projects are discussed. These are vehicle lateral controls for automated highway systems, hard disk drives and material handling mechanisms for printing engines. The author suggests that the faculty members specializing in design and control must act as leaders to bring mechatronics into the engineering curriculum.

Gardner [GAR 02] has described two projects that were given in a senior-level mechatronics elective course at Penn State University. While one project was successful, the other was a failure. The author has suggested the following measures to make a successful project:

– The project goal should be kept in mind. The project should be formulated so as to impart the maximum learning in the desired area.

– The instructor should preferably design and fabricate the project by himself before assigning it to students. In this way, the difficulty level of the project will be known.

– There should be a balance between the hardware and the software.

– The project should be open-ended enough to allow for innovation.

Grimheden and Hanson [GRI 05] have described the ongoing process of establishing mechatronics as an academic discipline with examples from Northern Europe. Vaughan *et al.* [VAU 08] have described a sophomore-level course titled “Creative decisions and design”. The course includes mechatronics and technical communication. The authors have emphasized the importance of team work. However, they also observed that in team work, students may not develop the capabilities in all the relevant areas and may divide the work according to their comfort/ability in an area. To alleviate this problem, during the early part of the course, each student was assigned individual projects involving fabrication. In the later half, the students were given team projects.

Habib [HAB 08] has described mechatronics and the required curriculum for teaching it. The author has emphasized the need to impart team, as well as, individual skills. There should be a balance between practice and theory. The author also emphasized the importance of a concurrent approach.

Ersoy [ERS 09] has discussed the problems due to different backgrounds of teachers of mechatronics. A case study of an institute in Turkey has been taken. The author has provided some suggestions for teachers of mechatronics. Teachers should motivate the students, facilitate to realize their potential and reward them for their success.

Wang *et al.* [WAN 09] have described the laboratory education at the CDHAW center of Tongji University in China. CDHAW stands for Chinese–German School of Applied Sciences. To properly train the students in mechatronics, four types of laboratories were developed – preliminary training laboratories, foundation laboratories, specialized laboratories and advanced laboratories. In the preliminary training laboratories, exposure to metal working and electrical or electronics is provided before theory learning. In foundation laboratories, the students verify the fundamentals of mechanics, physics, material science, circuit theory and so on. In the specialized laboratories, building blocks of mechatronics like control, sensors, actuators, PLCs, microprocessors and so on are introduced. In the advanced laboratories, students are supposed to work on their own projects. The main laboratories of CDHAW were the automatic control laboratory, the sensor laboratory, the PLC laboratory, the industrial communication laboratory and the modeling and simulation laboratory. The immediate plan was to develop an FMS laboratory.

Lee [LEE 10] has presented a survey of mechatronics education in 15 universities of South Korea. Some universities offer mechatronics course in the department of mechanical engineering, while at some places there is different division or department for mechatronics. A list of courses offered in the years 2002, 2006 and 2008 is provided in Table 2.2. The table provides some idea about the change in the trend in mechatronics education. Bradley [BRA 10] has discussed pertinent issues of mechatronics based on his personal experience of more than 20 years.

This brief review of the literature indicates the growing interest in mechatronics education. It also highlights some differences of perception in understanding mechatronics and its education. In the subsequent sections, the different types, methods and modes of mechatronics education will be discussed.

2.6. Common doubts regarding the discipline of mechatronics

The following question is often asked: Can mechatronics be called a separate discipline? This question has partly been answered in the beginning of the chapter. Mechatronics is different from either electronics or mechanics, in the same way that mechanical engineering is different from mechanics and thermodynamics. There can be experts who specialize in mechanics or thermodynamics, but a mechanical engineer is taught both the courses from an application point of view. Similarly, a mechatronics engineer will have the knowledge of electronics, mechanics and other disciplines from an application point of view. Someone has rightly said, "mechatronics practitioners will prototype the whole design, then the specialists in the various fields will take over the detailed design".

Academic year 2002	Academic year 2006	Academic year 2008
Industrial optics (2)	Opto-mechatronics (1)	Opto-mechatronics (1)
Manufacturing networks (1)	Computer network (3)	Computer network (2)
Medical engineering (1)	Bio-engineering (3)	Bio-engineering (2)
MEMS (1)	Micro/Mobile robots (2)	Micro/Mobile robots (2)
Virtual engineering (1)	Virtual engineering (2)	Virtual engineering (1)
Nonlinear control (1)	Assembly engineering (1)	Painting & polymers (1)
Multivariable control (1)	Web-based engineering (1)	Web-based engineering (1)
Intelligent system (2)	Discrete event system (1)	Discrete event system (1)
Computer graphics	Engineering documentation (3)	Injection molding (1)
Car electronics (1)	Car electronics (1)	Car electronics (2)
Energy engineering (1)	Embedded system (2)	Real-time control (1)
	Laser engineering (2)	Laser machining (1)
	Wind power systems (1)	Wind power systems (1)
	Computerized logistics (1)	Ship mechatronics (1)
		DSP application (2)
		Noise control (2)
		Ultrasonics (1)
		Display devices (2)
		Renewable energy (2)
		Semiconductor process (1)
		Rotor dynamics (1)
		Chassis design (1)
		Chassis control (1)
		RP practice (1)

Table 2.2. *University specific subjects in South Korea (the number in the parenthesis is the number of universities offering the course). With permission from [LEE 10]© 2010 Elsevier*

Many technical papers published in the *Mechatronics* journal emphasize the control aspect. This provides the impression that mechatronics mainly deals with products requiring controls. Control engineering finds a lot of application in mechatronics just as it finds application in the other areas. However, mechatronics deals with even those systems that do not need sophisticated control technologies. In fact, sometimes even in the products requiring control, the simplified techniques like fuzzy set theory and neural networks have been employed, which are quite different from conventional control methodologies.

Similarly, sometimes an impression is created that mechatronics is basically robotics. In fact, there have been books dealing with these two topics together (e.g. [STA 94]). While robotics is an example of mechatronic products, mechatronics is neither limited to robotics, nor does it have to cover all the in-depth aspects of robotics.

2.7. Characteristics of mechatronics education

Engineering education is generally based on single discipline activities founded on a bottom-up approach. The bottom-up approach builds on fundamental principles and concepts before integrating them in the form of a final product. The top-down approach first provides the overall idea of the final product, although not in very detailed form and then studies the subsystems of the system in detail. Mechatronics education has to follow a top-down approach, because it involves many disciplines and students have to get an idea as to how the various disciplines will be integrated. Integration of various disciplines is an integral part of mechatronics. Integration has to be carried out in a manner so that one and one become 11 instead of one.

Another feature of mechatronics education and practice is that they follow concurrent engineering (CE) practice. CE is a systematic approach to integrate concurrent design of products and their related processes, including manufacture and support. This approach is intended to make the developers from the outset consider all elements of the product lifecycle from concept through to disposal, including quality, cost, schedule and user requirements. CE is a business strategy that replaces the traditional product development process with one in which tasks are done in parallel and there is an early consideration for every aspect of a product's development process. This strategy focuses on the optimization and distribution of a firm's resources in the design and development process to ensure effective and efficient product development process. Just meeting the specification is not enough in CE. The designer has to keep in consideration, mass production, cost and quality. CE has often been practiced under different names such as Simultaneous Engineering, Lifecycle Engineering, Parallel Engineering, Multidisciplinary Team Approach, Integrated Product and Process Development and so on. The major objective of CE is to overlap the different phases of design to reduce the time needed to develop a product. It requires the simultaneous, interactive and interdisciplinary involvement of design, manufacturing and field support engineers to assure design performance, product support responsiveness and lifecycle reliability. Each team member is involved in all the aspects from the beginning.

In conventional design methodology, mechanical design should be done first followed by electrical or electronics and software design. This is schematically shown in Figure 2.4. This approach is quite inflexible and often distant from an optimum design. In the optimum design of a mechatronics product, at every stage of design, each discipline has to be involved. The design involves five phases: deciding specifications, conceptual design, embodiment design, detailed design and prototyping. Figure 2.5 shows a mechatronic design methodology that follows the CE approach.

During the specification design, conceptual design, embodiment design and prototyping, all the disciplines must work together. It can be said that at these stages a mechatronics engineer must be present to coordinate the effort of different specialists. Only in the detailed design phase, can the work be done by individual teams.

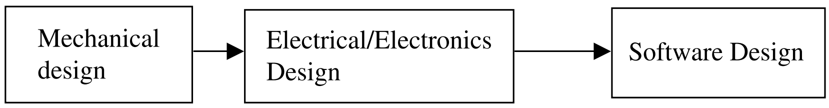


Figure 2.4. *Conventional design approach*

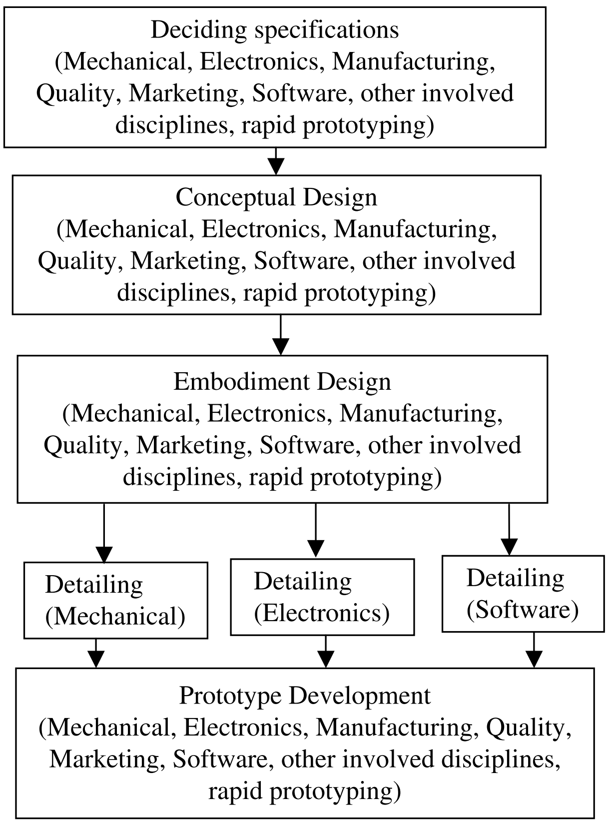


Figure 2.5. *A mechatronics design methodology*

Mechatronics students have to be trained in the philosophy of CE. Not only do the aspects of various disciplines have to be considered together, but also the manufacturing and marketing aspects have to be considered at the design stage itself. According to Brussel [BRU 96], mechatronics aims at a CE view on machine design.

Another feature of mechatronics education is that projects form a very important part of the education. There can be various miniprojects associated with courses. Finally, a major project can be carried out. The involvement of industry will help in defining the projects and in completing them successfully.

2.8. Incorporating mechatronics in the course structure of undergraduate students

Nowadays, at many places in India and abroad, mechatronics is taught as a separate discipline. However, in this section, the main focus is on teaching mechatronics to mechanical engineering students. The teaching of mechatronics can be started from the first year itself. This has to be done without providing additional load on the students. By taking the Indian Institute of Technology Guwahati curriculum as an example, it will be discussed how mechatronics education can be incorporated in it.

Table 2.3 shows the course structure for the first year, which is the common course for all disciplines. The course Engineering Mechanics can be replaced by a course on Introduction to mechatronics based on the following three reasons:

1) Students carry out thorough preparation on mechanics for various entrance examinations for engineering. This gives them extra-confidence after they are selected for engineering. As a result, they neglect this course in their first year of engineering and end up with little learning.

2) The first-year curriculum is a common course. The students in Biotechnology, Chemical Science and Technology and Design may not be interested in learning Engineering Mechanics beyond their pre-engineering level.

3) Like other courses, engineering mechanics follows the bottom-up approach, which does not provide any thrill to students. A course on the Introduction to mechatronics is expected to be a sound remedy for the above-mentioned reason.

Semester 1	L-T-P-C	Semester 2	L-T-P-C
MA-101 Mathematics-I	3-1-0-8	MA-102 Mathematics-II	3-1-0-8
CH-101 Chemistry	3-1-0-8	ME-101 Engineering mechanics	3-1-0-8
CH-110 Chemistry laboratory	0-0-3-3	CS-101 Introduction to computing	3-1-0-6
PH-101 Physics-1	2-1-0-6	PH-102 Physics-II	2-1-0-6
ME-111 Engineering drawing	2-0-3-7	BT-101 Modern biology	3-1-0-8
ME-110 Workshop-I	0-0-3-3	EC-102 Basic electronics laboratory	0-0-4-4
EC-101 Electrical sciences	3-1-0-8	CS-110 Computing Laboratory	0-0-3-3
HS-1xx English/HSS elective	3-0-0-6	PH-110 Physics laboratory	0-0-3-3
NCC/NSS/NSO	0-0-0-0	NCC/NSS/NSO	0-0-0-0

Note: L – lecture hours per week, T – tutorial hours per week, P – practical hours per week and C – credit.

Table 2.3. *First-year course structure*

The introductory course on mechatronics will contain the following salient topics:

1) definition and scope of mechatronics with examples of mechatronics products with a brief description about their

working: mechatronics in automobiles, aircraft, machine tools, process industries, laboratory instruments and so on;

2) basic mechanisms;

3) comparison of various electric motors and hydraulic and pneumatic systems;

4) introduction to PLC; microprocessors, microcontrollers and computer control.

A top-down approach may be followed in teaching of the course. Each topic can take about 10 lectures. The tutorial hour may be used to show various toys and models to small group of students. This will motivate students across the disciplines.

Table 2.4 shows the second-year course structure. In the third semester, mechanical engineering students have to do a course on electrical engineering that includes a laboratory component. This course can be replaced by a middle-level course on mechatronics. Infrastructure and expertise of an institution may be the major factors in either modifying this course or totally replacing it. There is no scope to include any other course related to mechatronics. However, as the students have already done an introductory course on mechatronics, some examples from the mechatronics area can be chosen. For example, the course on solid mechanics can include some examples of stress analysis of electronic devices.

In the fourth semester, the Mechanical Engineering Laboratory course can include some experiments on mechatronics. These can be on hydraulic and pneumatic control systems. The course on Workshop can include some miniprojects related to mechatronics.

Semester 3	L-T-P-C	Semester 4	L-T-P-C
HS-2xx HSS elective	3-0-0-6	XX-2xx Science elective	3-0-0-6
MA-201 Mathematics-III	3-1-0-8	HS-2xx HSS elective	3-0-0-6
CS-201 Object oriented programming and data structures	3-0-3-9	ME-202 Engineering materials	3-0-0-6
ME-201 Solid mechanics	2-1-0-6	ME-203 Advanced solid mechanics	2-1-0-6
ME-204 Fluid mechanics-I	2-1-0-6	ME-205 Thermodynamics	3-1-0-8
EC-205 Introduction to electrical engineering	3-0-2-8	ME-206 Fluid mechanics-II	2-1-0-6
ME-211 Machine drawing	0-0-4-4	ME-210 Workshop-II	0-0-0-6
		ME-212 Mechanical engineering laboratory -I	0-0-4-4

Note: L – lecture hours per week, T – tutorial hours per week, P – practical hours per week and C – credit.

Table 2.4. *Second-year course structure*

Table 2.5 shows the third-year course structure. Here, there is a scope to include a bit of mechatronics in every course. The course on Manufacturing Technology-I can include the fabrication of chips and microstructures. The course on mechanical measurements should include a lot of items from electronics. Signal processing should also be taught on this course. The design of machine elements course can be modified to include a selection of motors and other items. The kinematics of machinery and heat and mass transfer course should include a number of examples across disciplines. The laboratory courses in both the semesters can include a significant portion of mechatronics. There is already a course on control systems. This can be transformed to a course on the control of mechatronics systems. The course on machine design can include the design of mechatronics systems.

Semester 5	L-T-P-C	Semester 6	L-T-P-C
ME-301 Manufacturing technology-I	3-1-0-8	HS-3xx HSS elective	3-0-0-6
ME-302 Mechanical measurements	2-1-0-6	ME-306 Manufacturing technology-II	3-1-0-8
ME-303 Design of machine elements	3-1-0-8	ME-307 Machine design	3-0-2-8
ME-304 Kinematics of machinery	2-1-0-6	ME-308 Dynamics of machinery	2-1-0-6
ME-305 Heat and mass transfer	3-1-0-8	ME-309 Control systems	3-1-0-8
ME-310 Mechanical engineering laboratory-II	0-0-4-4	ME-311 Mechanical engineering laboratory-III	0-0-4-4
ME-321 Applied thermodynamics-I	2-1-0-6	ME-322 Applied thermodynamics-II	2-1-0-6

Note: L – lecture hours per week, T – tutorial hours per week, P – practical hours per week and C – credit.

Table 2.5. *Third-year course structure*

Table 2.6 shows the course structure for the final year (i.e. fourth year). In the seventh semester, one elective can be replaced by a compulsory course on mechatronics that can be a 2-0-2-6 type course, with two hours of lectures and two hours of practicals per week. As the basic experiments in mechatronics would be covered in laboratory courses, the laboratory in mechatronics course will essentially be for miniprojects.

In this way, mechatronics can be incorporated in the existing curriculum. The challenges are in motivating the faculty members to adapt to this change and in making available good textbooks and laboratory facilities.

Semester 7	L-T-P-C	Semester 8	L-T-P-C
ME-399 Summer training	PP/FF 0	HS-4xx HSS elective	3-0-0-6
XX-4xx Open elective-I	3-0-0-6	XX-4xx Open elective-II	3-0-0-6
ME-401 Industrial engineering operations research	3-1-0-8	ME-xxx Departmental elective-III	3-0-0-6
ME-xxx Departmental elective-I	3-0-0-6	ME-xxx Departmental elective-IV	3-0-0-6
ME-xxx Departmental elective-II	3-0-0-6	ME-499 Project-II	0-0-0-16
ME-411 Mechanical engineering laboratory-IV	0-0-4-4		
ME-498 Project-I	0-0-8-8		

Note: L – lecture hours per week, T – tutorial hours per week, P – practical hours per week and C – credit.

Table 2.6. *Fourth-year course structure*

2.9. Mechatronics for postgraduate students

Postgraduate students come from various backgrounds. Therefore, the course should start from basic level and go up to intermediate or advanced level. At the Indian Institute of Technology Guwahati, the course "Mechatronics and Manufacturing Automation" fulfils that requirement. The course syllabus is as follows:

Definition of mechatronics; mechatronics in manufacturing, products and design; Review of fundamentals of electronics; Data conversion devices, sensors, microsensors, transducers, signal processing devices, relays, contactors and timers; Microprocessors, controllers and PLCs; drives: stepper motors, servo drives; Ball screws, linear motion bearings, cams, systems controlled by camshafts, electronic cams, indexing mechanisms, tool magazines and transfer systems; Hydraulic systems: flow, pressure and direction control valves, actuators and supporting elements, hydraulic power packs and pumps; Design of hydraulic circuits; Pneumatics: production, distribution and conditioning of compressed air, system components and graphic representations, design of systems; Description of PID controllers; CNC machines and part programming; Industrial robotics.

The course has three lectures per week. The laboratory portion is supported by a course having a laboratory class of six hours per week. The syllabus of the course is as follows:

Measurement of cutting forces, surface roughness, tool wear, dimensional deviation and vibrations in machining; Measurement of chip thickness ratio and temperature in machining; Determination of the mill modulus of a laboratory rolling mill; Measurement of micro-hardness; ring compression test for the estimation of friction in metal forming; Open-die forging: observation of bulging and forging load; *Hydraulic and pneumatic systems; Sensors and transducers; PID controller; Study of robots; CNC programming; Design of simple electronic circuits; Microprocessors and PLCs for manufacturing applications*; Electrochemical machining, laser and plasma cutting; Vacuum coating.

In the above courses, the italicized portion is directly relevant to mechatronics.

At present, these courses are compulsory for the Computer-Assisted Manufacturing stream of M.Tech. and optional for other streams. A lot of training in mechatronics can be imparted through the M.Tech. thesis of the student.

2.10. Planning of a mechatronics program at postgraduate and undergraduate level

Several universities are now running a postgraduate program in mechatronics [ACA 97, SAL 03]. Some of them are integrated programs of four-to-five years duration. Two-year programs usually admit students from mechanical and electrical or electronics background. The course structure differs from country-to-country and university-to-university. A thrust on laboratory components is an essential feature of a mechatronics program.

A typical postgraduate-level program consisting of four semesters can be divided into two semesters of course work and two semesters of a thesis related to mechatronics design and fabrication. A tentative course structure for the two semesters is provided in Table 2.7. The students of mechanical/production/industrial or electrical/electronics background can be admitted into the program. Some difference in the training of mechanical and electrical groups can be made by means of compulsory and elective courses.

At undergraduate level, the course should be a judicious mixture of mechanical, electrical, electronics and computer science. Many universities are offering the four-year undergraduate program in mechatronics and we can refer to their Web page for the course structure. Some references [ACA 97, SAL 03] also provide the undergraduate program structure. The following guidelines can be considered while designing a four-year program in mechatronics:

1) A top-down approach should be adopted. Initially, there should be some courses providing the overall exposure of mechatronics systems. This will motivate the students and help in a better grasping of the subject.

2) The laboratory component should be more than that of existing traditional engineering courses. It can be from 40% to 50%.

3) Miniprojects should be part of the course structure starting from second year to third year. A miniproject can be of one-semester duration. Thus, each student will be able to carry out a total of four miniprojects in the course duration.

4) There should be a final year project of one-year duration.

5) Some courses from the basic sciences and humanities should also be provided.

Course	Semester 1	Semester 2
Compulsory course-I	Mathematics including numerical methods and programming. The course can have three lectures per week and 2 h of programming laboratory.	Control of mechatronic systems. Preferably the course should have two lectures and one 2 h laboratory class each week and should include pneumatic, hydraulic control and fuzzy set-based control.
Compulsory course-II	Elements of mechanical engineering (for students of electrical or electronics background) or elements of electrical or electronics (for students of mechanical background). This course can have three lectures per week.	Design methodology for mechatronics product. Preferably 2 h of lectures and 2 h of laboratory work per week, where the students can work on miniprojects.
Compulsory course-III	Mechatronics laboratory providing exposure of mechatronic products, sensors, PLCs, microprocessor, hydraulic and pneumatic. The course should have two classes of 3 h duration each.	Advanced mechatronics. It can have three lectures per week and can include advanced topics in sensors, actuators and embedded systems.
Two elective courses in each semester	A number of elective courses can be floated depending on the expertise of the department and demand of the students. Examples: finite element modeling of mechatronic systems, optimization, soft computing, real-time computing systems, advanced digital signal processing, image processing, robotics, CAD-CAM, microprocessors, digital control system, advanced microelectronic circuits	

Table 2.7. *Tentative course structure for two-year MS program in mechatronics*

2.11. Some examples of mechatronics projects

Projects are a very important part of mechatronics education. The technology of mechatronics is rapidly changing and it is not possible to cope with these changes by textbook reading alone. By executing the project, the student gets familiar with many technological developments. At the same time, the project helps the student in understanding design, manufacturing, purchasing and the testing aspects of mechatronics. In this section, some projects carried out on the final year undergraduate and postgraduate programs of the Indian Institute of Technology Guwahati are briefly described to give an idea of the types of projects.

2.11.1. *Design and fabrication of a mechatronic wheelchair*

A joystick-operated mechatronic wheelchair was designed and fabricated at IIT Guwahati [DHA 02, KOD 03]. Two independent DC motors controlled by a pulse width modulation scheme run the two wheels of the wheelchair. Turning is accomplished by varying the speed of the motor. The salient feature of this project is that the design was modular and that it can be retrofitted to conventional wheelchairs. Due to PWM control, the energy efficiency was improved. Figure 2.6 shows the block diagram of the power module of the wheelchair. As a result of the project, students learned rehabilitation needs, mechanical design, ergonomics, aesthetics and electronics. Figure 2.7 shows the testing of the wheelchair. The project got publicity in local newspapers, which motivated the students and technicians involved in the project.

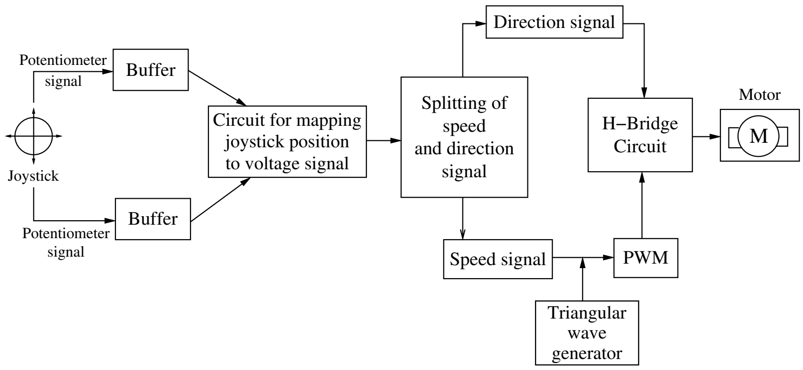


Figure 2.6. *Structure of a power module*

Figure 2.7. *Testing of a mechatronic wheelchair*

2.11.2. *Automatic gear changing system for cars*

In this project, an automatic gear changing system for cars was developed [RAJ 04]. The system is developed as a module that can be retrofitted to conventional cars. The feedback of engine speed and accelerator pedal position is taken as input to cause x and y movement of the lever through rack and pinion drives. Based on a fuzzy logic program, a microcontroller actuates two motors to bring the gear-shifting lever into a particular position. During the gear shifting operation, the clutch paddle gets automatically disengaged. Figure 2.8 shows a prototype of the gear change module. In this project, the students learned about the fabrication of a rack and pinion drive and the operation of the microcontroller.

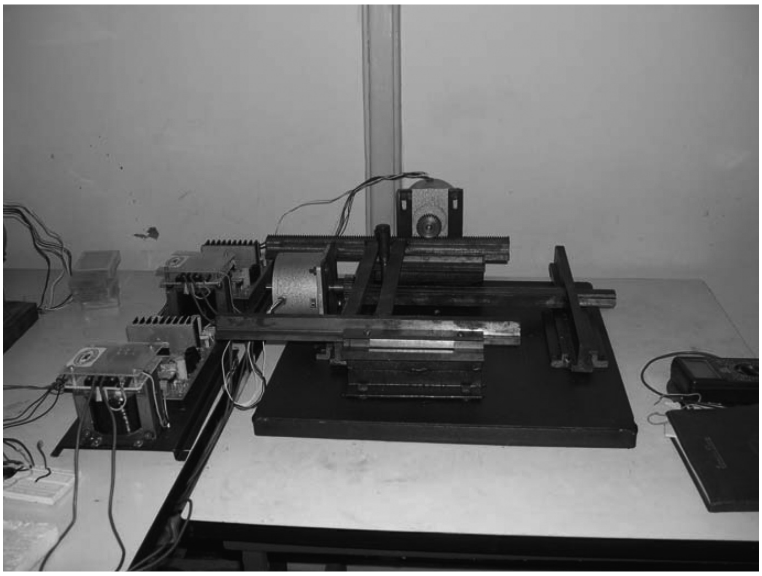


Figure 2.8. *Prototype of gear change module*

2.11.3. *Design and fabrication of robots*

A number of projects were about designing and fabricating specific types of robots. Initially, a three-axes Cartesian robot with magnetic gripper was developed [CHE 01]. This robot was controlled by a microprocessor. Later on, a PC–controlled, shop floor inspector robot (Figure 2.9) was developed [BAN 01]. This was a (four-axis and gripper) stepper motor-driven robot. It has a digital vernier caliper, which can be used for measuring the dimensions of machined components. The inspection data can be stored in the PC. Thus, the robot was used for segregating good and defective parts. The cost of manufacturing this robot was around $1,000 in 2001. This robot can also be used as an educational robot as it can carry out a variety of tasks and can be easily programmed using C language.

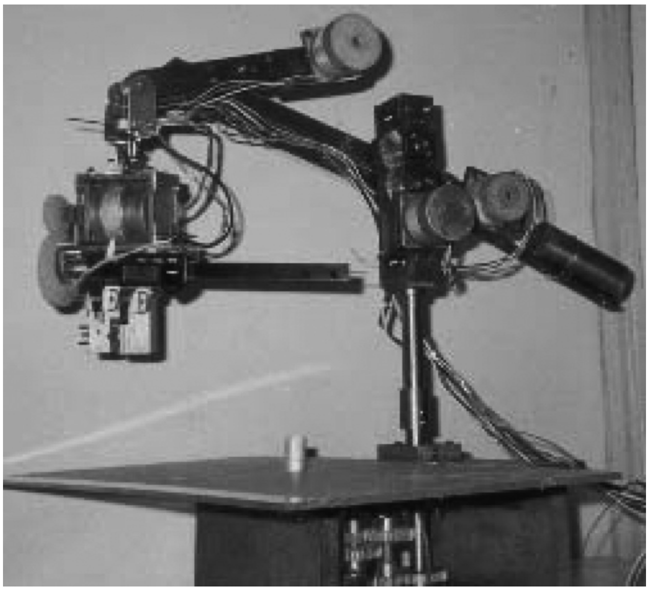


Figure 2.9. *Shop floor inspector robot developed in a B.Tech. project*

2.11.4. *Design and fabrication of an electronic cam*

A cam is used to convert rotary motion into a reciprocating motion. Depending on the characteristics of motion of the reciprocating follower, a cam (in the form of disk or drum) is fabricated with a particular profile. In the 19th and the first half of the 20th Century, cams were very popular in automatic machines. Even now, they are used at several places. One common example is the opening and closing of inlet and exhaust valves of a four-stroke engine. The design and manufacturing of a cam is a tedious task and a new cam has to be used if the characteristics of motion changes.

It is possible to replace a cam and the follower system by a stepper or servo motor–based system. This was attempted in a B.Tech. project [RAW 02]. The rotary motion was converted into reciprocating motion by using a power screw and nut combination. The power screw was driven by a motor, which was programmed by a microprocessor and a nut acted as a follower.

2.12. Conclusion

In this chapter, various aspects of mechatronics education are described. There are two prominent ways of providing mechatronics education – by incorporating the mechatronics courses in the regular curriculum of mechanical engineering and by having a separate program of mechatronics. Both these modes of education are discussed. Mechatronics education has to follow a top-down approach and projects form a very important part of mechatronics education.

Two major challenges along with the possible measures to tackle them are as follows:

1) There is difficulty getting instructors for mechatronics education, as the discipline is very young and persons trained in mechatronics are scarce. Over a period of time, a sufficient number of trained mechatronics graduates will be available and instructor-related problems will be lessened. To tackle this problem for the time being, guest faculty members from other departments and industry can be hired.

2) Laboratories and projects form a very important component of mechatronics education. Limited resources in academic institutes may discourage the progress of

mechatronics education. One way to tackle this problem is to involve industries, which can fund the projects, in mechatronics education.

2.13. Bibliography

[ACA 96] ACAR M., PARKIN M.R., "Engineering education for mechatronics", *IEEE Transactions on Industrial Electronics*, vol. 43, pp. 106–112, 1996.

[ACA 97] ACAR M., "Mechatronics challenge for higher education world", *IEEE Transactions on Components, Packaging, and Manufacturing Technology-Part C*, vol. 20, pp. 14–20, 1997.

[BAN 01] BANALA S.K., DHANDA P., Design and fabrication of a robot of industrial utility, B.Tech. Project Report, IIT Guwahati, 2001.

[BRA 10] BRADLEY D., "Mechatronics – more questions than answers", *Mechatronics*, vol. 20, pp. 827–841, 2010.

[BRU 96] BRUSSEL H.M.J.V., "Mechatronics – a powerful concurrent engineering framework", *IEEE/ASME Transactions on Mechatronics*, vol. 1, pp. 127–136, 1996.

[CHE 01] CHENNURI S.B., Design and fabrication of a 3-axis robot using mechatronics approach, M.Tech. Thesis, IIT Guwahati, 2001.

[DHA 02] DHARIWAL J., Conceptual design of a powered wheelchair, B.Tech. Project Report, IIT Guwahati, 2002.

[ERS 09] ERSOY S., "Defining of conceptions related to their department of candidate teacher of mechatronics education", *Procedia – Social and Behavioral Sciences*, vol. 1, pp. 2117–2125, 2009.

[FRA 93] FRASER C.J., MILNE J.S., LOGAN G.M., "An educational perspective on applied mechatronics", *Mechatronics*, vol. 3, pp. 49–57, 1993.

[GAR 02] GARDNER J.F., "Two projects for undergraduate mechatronics class: success and failure", *Mechatronics*, vol. 12, pp. 337–342, 2002.

[GAR 98] GARIISON E., A History of Engineering and Technology: Artful Methods, CRC Press, London, 1998.

[GRI 05] GRIMHEDEN M., HANSON M., "Mechatronics – the evolution of an academic discipline in engineering education", *Mechatronics*, vol. 15, pp. 179–192, 2005.

[HAB 08] HABIB M.K., "Interdisciplinary mechatronics engineering and science: problem-solving, creative-thinking and concurrent design synergy", *International Journal of Mechatronics and Manufacturing Systems*, vol. 1, pp. 4–22, 2008.

[HAN 94] HANSON M., "Teaching mechatronics at tertiary level", *Mechatronics*, vol. 4, pp. 217–225, 1994.

[KOD 03] KODATI P., Fuzzy set based design and fabrication of the power module of a mechatronic wheelchair, B.Tech. Project Report, IIT Guwahati, 2003.

[LEE 10] LEE J.-W., "Investigation of mechatronic education in South Korea", *Mechatronics*, vol. 20, pp. 341–345, 2010.

[LYS 02] LYSHEVSKI S.E., "Mechatronic curriculum – retrospect and prospect", *Mechatronics*, vol. 12, pp. 195–205, 2002.

[RAJ 04] RAJAN S., JHA V.C., Design and fabrication of an automated manual transmission system, B.Tech. Project Report, IIT Guwahati, 2004.

[RAW 02] RAWAT A., Design, fabrication of an electronic cam mechanism and the study of cam mechanism and their shape optimization, B.Tech. Project Report, IIT Guwahati, 2002.

[SAL 03] SALAMI M.J.E., MIR-NASIRI N., KHAN M.R., "Development of mechatronics engineering degree program: challenges and prospects", *International Journal of Engineering Education*, vol. 19, pp. 537–543, 2003.

[STA 94] STADLER W., *Analytical Robotics and Mechatronics*, McGraw-Hill, New York, 1994.

[TAN 98] TAN K.K., LEE T.H., DOU H.F., LIM S.Y., "Various developments in mechatronics in Asia", *Mechatronics*, vol. 8, pp. 777–791, 1998.

[TOM 02] TOMIZUKA M., "Mechatronics: from the 20th to 21st century", *Control Engineering Practice*, vol. 10, pp. 877–866, 2002.

[VAU 08] VAUGHAN J., FORTGANG J., SINGHOSE W., DONNELL J., KURFESS T., "Using mechatronics to teach mechanical design and technical communication", *Mechatronics*, vol. 18, pp. 179–186, 2008.

[WAN 09] WANG Y., YING Y., XIE C., WANG H., FENG X., "Mechatronics education at CDHAW of Tongji University: Laboratory guidelines, framework, implementations and improvements", *Mechatronics*, vol. 19, pp. 1346–1352, 2009.