

# Mechatronics for Engineering Education: Undergraduate Curriculum\*

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*Mechatronics is a synergistic combination of electrical and electronic engineering, computer technology and control engineering with mechanical engineering that forms a crucial part in the design, manufacture and maintenance of a wide range of engineering products and processes. Engineering education with a mechatronics curriculum provides the necessary core technologies for the future engineers with multi-disciplinary background. This paper outlines the mechatronic engineering curriculum of an undergraduate degree at the City University of Hong Kong, which aims to provide the integrated learning experience.*

## INTRODUCTION

SMART MACHINES and intelligent systems are rapidly changing the world perspective in engineering education. Information processing ability of the products and processes is the key issue to make them smart and intelligent. Machines are becoming functional computers and the components in these systems are often microprocessor based, and they communicate over computer buses. The mechanical devices become mechatronic products by means of intelligence derived from information that spans the entire product, combining precision mechanical elements with electronics and computers. The design and development of mechatronic products and processes require engineering education to integrate the key technology areas. The increasing interest worldwide on mechatronic education is evident from the growing number of undergraduate and postgraduate courses now being offered and many textbook publications [1–13].

Mechatronics has emerged as one of the new and exciting fields on the engineering landscape, subsuming parts of traditional engineering fields and requiring a broader approach to the design of systems [10, 11]. It denotes a rapidly developing, interdisciplinary field of engineering that deals with the design of products whose function relies on the synergistic integration of mechanical, electrical, and electronic components connected by control architecture [14]. The primary disciplines involved in the design of mechatronic systems include mechanics, electronics, controls and computer science. A mechatronic system designer must assemble analog and digital circuits, microprocessors and computers, mechanical devices, sensors and actuators, and controls so that the final design achieves a desired goal.

Mechatronics is basically the application of precision mechanical engineering, control theory, computer science, and electronics to the design process in order to create more functional and adaptable products. Although forward thinking designers and engineers have been using the mechatronics philosophy for years [15, 16], it has become a significant trend in recent years with marked influence on the product development process. With severe international competition in the manufactured products with high functionality and reliability, the nature of engineering education in coming years will have more focus on mechatronics curriculum. The real challenge to mechatronics education is training for the creative and practical phases of mechatronic product design involving analysis, synthesis, development and engineering research in the multidisciplinary fields of education.

The integration of mechanical engineering, electrical and electronic engineering, and computer technology forms the key elements of a true mechatronics solution by effectively combining these disciplines. The full potential of mechatronics is only available if the approach is from an integrated standpoint from the start. With evolutionary advances in computers, sensors, actuators and the rest, the mechatronics approach has changed the way products are designed and produced. From the educational viewpoint, the focus of mechatronic engineering is to teach the basics of mechanics, electronics, computers and controls with applications to integrate all these into the design process [17, 18]. Although the inputs to the concept of mechatronics are in a continual state of flux, particularly microprocessor technology, there are clearly identifiable axioms that form the core material in a curriculum design. In this interdisciplinary learning, the real issues are related to comprehensive and balanced curriculum design.

\* Accepted 5 June 2003.



Fig. 1. Courses in mechatronics engineering undergraduate curriculum.

In many universities worldwide, mechatronics has been incorporated into traditional engineering curricula. The level of mechatronics education in a majority of the cases appears to have been confined to one or two courses at an appropriate level for undergraduate or postgraduate curriculum [6, 7]. A number of textbooks published on mechatronics also support the view of general understanding rather than intense treatment [12, 13]. While the mechatronics curriculum in general are oriented more towards robotics at graduate level, the focus of the undergraduate curriculum on mechatronics education at the City University of Hong Kong is strongly on in-depth learning to acquire integrated knowledge using theory, experimentation and group design projects [4, 5, 9]. The paper reviews the nature and structure of the mechatronics education, and the successful implementation of the undergraduate curriculum in training mechatronics engineers that have been under continuous improvement since 1992 at the City University of Hong Kong.

## UNDERGRADUATE CURRICULUM DESIGN

### *Aims and objectives*

The basic aim of the undergraduate curriculum is to train mechatronic engineering graduates who are capable of integrating the diverse disciplines of mechanical, electronic and computer engineering with a view to design and develop high value-added discrete products of mechatronic nature. The curriculum design is balanced to enable the students to develop:

- a fundamental understanding of the analysis and design of mechanical and electronic devices;
- a broad understanding of the utilization of computers in control and communication;
- a basic understanding of the principles of motion control;
- an overview of manufacturing technology and its influence on product design;
- an in-depth understanding of the practice of product design, and the utilization, operation and maintenance of modern engineering equipment

in manufacturing through appropriate optional subjects.

The comprehensive nature of the curriculum design is expected to develop creative design abilities to the product development process through appropriate group/individual activities of students to:

- coordinate multidisciplinary projects considering trade-off factors with available technology options with respect to cost, schedule and risk;
- work as an effective member of a design team; and
- communicate technical results to specialists and non-specialists.

## CURRICULUM STRUCTURE

There are three levels of courses in the curriculum as indicated in Fig. 1. The fundamental level courses emphasize the basic principles and concepts, covering a broad spectrum of analytical and practical skills. The intermediate level courses are more advanced and provide the essential background for specialized knowledge. The advanced level courses emphasize applications with an integrative approach to the design and development of mechatronic products.

The curriculum structure is organized in such a way that the courses are taught in a sequential manner with prerequisite requirements to satisfy. The interactions between the course groups are shown in Fig. 2. The courses at the fundamental level are basically supporting courses to help the students to acquire the basic knowledge and practical skills. Intermediate level courses are more advanced and form into essential themes under mechanical, electronic, and microprocessors and control engineering. The advanced level courses and elective courses are integrative in nature to provide hardware design and software design knowledge. The small group design project provides the students with a platform for creative and practical phases of engineering design involving analysis and synthesis, and prototype development.

The courses form into essential design themes under mechanical, electronic, and control

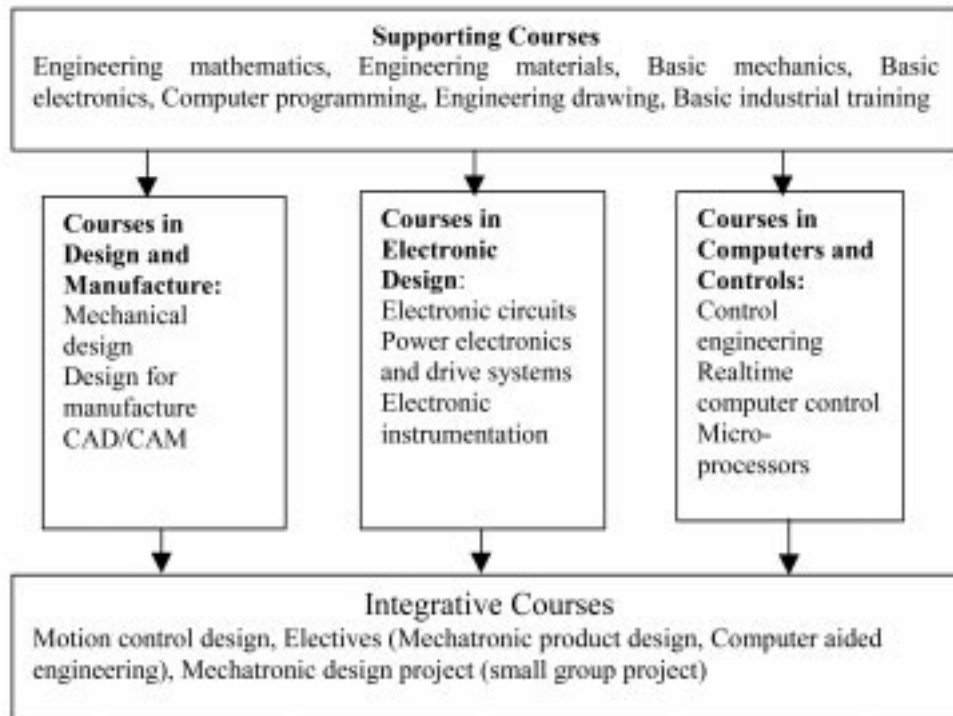


Fig. 2. Interactions between course groups.

engineering involving courses at different levels, and culminate in the implementing of a design project. The scope and depth of treatment of the courses are well balanced to match the interdisciplinary nature of mechatronics education.

### TEACHING AND LEARNING METHODS

In view of the multidisciplinary nature of the curriculum structure with emphasis on mechatronics in engineering design, the courses have a significant proportion of time devoted to 'active learning' through 'doing' as opposed to 'passive learning' through lecture sessions [19–22]. About 60% of the total contact time in the courses is devoted to laboratory, project, tutorial and training through case studies where the students are largely in the active learning mode. The laboratory work the students undertake has a mixture of standard structured experiments, student-centered activities (SCA) with practical mini-projects, integrated studio teaching (integration of lecture, tutorial and laboratory), problem-based learning, and case studies using reverse engineering of standard commercial engineering products. Much of these activities are done in small groups, thus simulating the team environment of practical work place in industry.

In the student-centered activity (SCA), each group of 4 or 5 students are assigned a substantial open-ended problem that requires the application of subject material taught in the course. The group must autonomously plan and implement the solution of the problem. The role of the instructor is

limited to providing technical consultation and monitoring/assessing the students' performance. The assessment of each student's performance will be based on motivation and scientific objectivity demonstrated by the student, and a brief written report [19, 20].

Integrated studio teaching is another innovative teaching and learning method adopted for teaching the courses in basic electronic engineering. Lectures, tutorials and laboratory experiments are combined into some form of integrated approach with a significant amount of collaborative learning, group projects and 'student-teaching-student' techniques. This approach promotes hands-on interactive student participation focusing on problem-solving methods, providing immediate application and immediate feedback to both learner and instructor [21, 22].

The teaching and learning methods in the curriculum are devised in such a way that the students learn in a sequential manner within a theme, and different themes simultaneously. Brief summaries of the appropriate courses forming different themes of the curriculum framework are indicated in the following paragraphs. The summaries also include an outline of the specific teaching and learning methods used, and the assessment procedures.

#### *Mechanical design theme*

Mechanical design theme aims to provide a fundamental understanding of the principles and practice underlying the design and prototype building of mechanical systems. The theme begins with engineering analysis to equip the

students with fundamental understanding of the basic principles of the mechanics of materials and machines. The teaching and learning of the related courses emphasize practical and active learning approaches with laboratory experiments, mini-projects in the form of SCA, and computer-based courseware [19, 20]. In the SCA, the students participate in mini-projects on mechanical analysis with simple design problems as small group activity. In this activity, the students design and build a working engineering example (e.g. a projectile mechanism; a power transmission system in conjunction with a small vehicle) by using the knowledge they gained in the engineering analysis courses.

The theme continues with the study of mechanical design process and manufacture through the study of selected topics and design case studies. This provides the students with an understanding of common mechanical design techniques used in industry for realizing engineering products using commercially available mechanical elements as well as discrete parts specifically designed and manufactured. An essential part of the theme includes a broad understanding of classical and modern manufacturing technologies used in the context of design for manufacture.

#### *Electronic design theme*

Electronic design theme begins with basic electronic engineering for the understanding of the principles of analogue and digital electrical circuits, electrical motors and systems. A substantial part of the theme includes courses on electronic instrumentation, power electronics and drive systems. Here, the students study the fundamentals of memory devices and structures, and the design techniques involved in sequential circuits and digital controllers, and obtain an understanding of the principles and design of operational amplifiers, signal transmission and instrumentation systems.

In all the courses, the students are trained with lecture, tutorial and laboratory components. Over the years, the composition of teaching and learning in this theme is changing from traditional methods to more active modes. The basic electronic engineering courses are taught in integrated teaching studio environment involving integration of lecture, tutorial and laboratory components, with a significant amount of collaborative learning, group projects and 'student-teach-student' techniques [21, 22].

#### *Control design theme*

The courses in this theme include control principles, computer programming, microprocessors, real-time computer control, and motion control design. Together with the mechanical and electronic design themes, it provides an in-depth understanding of the principles of control, the common range of control elements and their application in the development of mechatronic control systems

with emphasis on motion control. The computer courses in the theme aim to develop a fundamental understanding of the principles of programming, data structures, the structure of computer hardware, software engineering, communications and databases, which are essential for the software design associated with mechatronic products.

The control design theme is an integrating theme where the students acquire practical knowledge of feedback control systems using both analogue and digital (computer-controlled) strategies together with the design principles and techniques associated with power electronics and drive systems. The integrative learning takes 'hands-on' approach with the course on motion control design in this theme where the students are assigned substantial motion control design task as a student-centered activity (SCA). The mini-project design task requires the students to integrate mechanism design with digital electronics, microprocessor interfacing, software engineering, feedback control theory, power electronics, servomotor design, etc. The examples covered here include sensors, human-machine interfaces, machine-machine interfaces, systems design methodology and practical case studies.

#### *Design project theme*

The design project theme forms an ideal platform for the students' integrative learning experience. It is a system-level thinking attitude that involves the interaction of different technologies to form an optional concept. In the design projects, the systems approach provides a design solution to a specific problem by placing emphasis on satisfying the overall system objectives.

The design project theme aims to drive the creative, analytical, application and integration skills of the students through the planning and execution of a substantial design task as a small group activity of 3 to 5 students. The project objectives involve substantial design activities requiring the application of knowledge related, predominantly, to mechanical, electronic and control themes. In the initial part of the design project, the students define the functional objectives of the product to be designed, justify technical/economic requirements and come up with a set of feasible alternatives for the design strategy. They select the 'best' alternative, sub-divide the product into subsystems, and identify the requirements of each subsystem and allocate the work appropriately among the group members. Each student works independently in the design sub-tasks allocated to him/her in the later part of the design project while continuing to interact with other members in the group in order to ensure compatibility. The design projects end with testing of a prototype of the product at the breadboard level, and the project presentation. Though group achievement is considered as the most valuable outcome of these projects, the assessment is also based on the extent of achievement, scientific basis,

intellectual depth and creativity, on an individual basis, to encourage and recognize individual excellence.

Management of the design projects, teaching methods and assessment procedures are important issues in implementing the projects effectively. A project management team consisting of academic staff with different core areas of expertise is charged with the responsibility of ensuring uniform application of assessment standards across all the projects, and the individual students in each group. Appropriate guidelines for the project implementation are issued to the design project advisors (updated each year in the light of the experience in the previous years). The project advisors play a key role in ensuring academic success of the design projects by providing technical consultation, budgeting, industrial support for industry-sponsored projects, and continuously monitoring the progress of the project and each student member's contribution at individual level. At the end of the project period, each design project group makes a presentation of the outcome, and each student member gives an account of his/her contribution to the project and the problems encountered during the period.

The performance assessment of each student is based on four distinctive elements:

- student motivation, effort and evidence of understanding;
- project achievement with heavy emphasis placed on the individual student's accomplishment;
- project report composition and contents;
- presentation skills.

In order to ensure uniform assessment standards across all the design projects, the results of the outcome are subjected to a peer assessment review procedure devised by the project management team [23].

The design projects undertaken by the students of the mechatronic engineering program at the City University of Hong Kong show implementation of the projects at a systems concept with the interaction of different core technologies. These involve mechanical subsystems, sensors, micro-processor-based controllers, actuators, and human-machine interfaces. Typical examples of the design projects implemented are [9]:

- high-technology engineering products (service robots for glass wall cleaning of high-rise

buildings, self-navigated vacuum cleaning hospital robots);

- consumer products (smart vacuum cleaner, electronic home for intelligent security);
- process mechatronic equipment (CNC gem stone/diamond polishing machine, CNC mini turning and milling center);
- fun-play products (micro-robot soccer, entertainment robot).

Successful implementation of the design projects depends on the resources that can be provided. The very nature of the projects in this discipline requires a variety of resources. These include multidisciplinary staff, experimental and training facilities and contemporary research program in the subject area. The Department of Manufacturing Engineering and Engineering Management at the City University of Hong Kong has a good mix of staff expertise in the mechanical, electrical/electronic, computer and control engineering disciplines, an array of laboratory and training facilities, and complimentary research activities under the Centre for Intelligent Design, Automation and Manufacturing (CIDAM). Active participation in competitive activities such as participation in several micro-mouse and robot ping-pong competitions in Hong Kong and UK, micro-robot world soccer championship in Brazil, etc. add the international dimension and exposure of our students and researchers associated with this program.

## SUMMARY

Mechatronics is a design philosophy underpinned by a multidisciplinary technology for producing an array of engineering devices with smart components, intelligent systems, robots and flexible manufacturing facilities. The design and development of mechatronic products and processes requires a new breed of engineers capable of integrating key technology areas comprising mechanical, electronic and computer engineering. The undergraduate curriculum has been geared to develop such engineering graduates. The success of such an undergraduate programme is underpinned heavily by the availability of a variety of resources. These include multidisciplinary staff, experimental and training facilities, and an active research programme in the subject areas.

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