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Development of Mechatronics Engineering Degree Program: Challenges and Prospects*

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It is now becoming common practice to include some courses in mechatronics in the traditional electrical and mechanical engineering programs. Whilst many engineering faculties have realized the need for a full-fledged multidisciplinary mechatronics engineering program, only in very few places have such programs been developed along the lines of other engineering programs. The justification for the mechatronics engineering program becomes evident, as today's engineers must be acquainted with subjects that are not taught or given much emphasis in the traditional engineering curriculum. A good knowledge in those subjects, is however required if our graduate engineers are to be relevant to industry with time. The challenges in developing such program in terms of curriculum planning, laboratory facility needs and staff requirements are discussed in this paper. Whilst there are immense advantages of such a discipline, its success depends on a balanced curriculum with good laboratory facilities and appropriate industrial links, positive attitudes and well-oriented academic staff as well as students having the ability to cope with diversified subjects.

INTRODUCTION

THERE IS A growing demand in industry for a special breed of engineers having skills to conveniently and successfully handle multiple tasks of diversified origins. It is expected that this trend would continue, especially as sophisticated equipment would be needed to match the high quality of products and services demanded by the society. Moreover, the infusion of microelectronics into machinery to ease its control or monitoring also implies that today's engineers should have an in-depth and broad-based engineering knowledge to enable them to perform the range of duties that industry may demand. Mechatronics, being an integrated engineering discipline, provides a solution to the problem of designing engineering curriculum that will be flexible and yet focused in satisfying the needs of a contemporary industry. Reports of survey carried out in Japan [1] and Malaysia [2] coupled with the MIT commission's recommendations [3] and other recent publications [4] have clearly indicated the need of graduate engineers from such a program.

Depending on the school of thoughts, mechatronics has been given arrays of definitions [4–8] and interpretations, leading to different mechatronics curricula. By and large, it is universally accepted that mechatronics refers to a design methodology that encompasses a range of subjects such as macro and micro machinery, sensors and instrumentation technology, drive and actuator technology, computer-based or embedded real-time microprocessor systems, and real-time software to enhance system performance and improve quality of products. Quite often this requires the introduction of electronics, microprocessors and computers into mechanical systems in order to improve the quality factors such as higher speed of operation, greater flexibility, precision, reliability and ease of redesigning or reprogramming. Hence, different breeds of engineers having appropriate skills and knowledge would be needed to work with such systems. Consequently, there is a need for new direction in the teaching of engineering if our graduates are to be relevant to industry over time.

One approach of achieving this is to include a few relevant courses in either mechanical or electrical engineering curricula so as to enhance the quality of our graduate engineers. This approach can pose some problems. Studying mechatronics under the guidance of different engineering departments does not make the students fit into any real appropriate program and students feel themselves being in nowhere. An alternative approach is to have a full-fledged mechatronics engineering department that allows the reflection of urgent industry needs. Such an arrangement allows students to be more focused on the integrated engineering approach, which is most required in this field. It is in the light of this that the faculty of engineering at the International Islamic University Malaysia (IIUM) decided to have a separate department for the mechatronics engineering

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program. This department is unique as it is the first in Malaysia. However, there are a lot of challenges in the development and implementation of this program so that it can gain global recognition since our students come from all over the world.

MECHATRONICS PROGRAM IN UNIVERSITIES

Though Japan started first with the Mechatronics concept of product development they did not put much emphasis in producing mechatronics graduates, rather they formed mechatronics research groups both in the universities and the industries to undertake research. Moreover, they develop mechatronics specialists through training programs in the industries. Other than Japan, many Asian countries [6] are gradually introducing mechatronics engineering programs in their universities. Similar trends are observed in the Australian continent as well. Thus, it is clear that mechatronics, being a demand of the modern industries, is gradually penetrating into the academic world of universities as well. The course outline of a four-year mechatronics engineering program at the University of Western Australia (UWA), Australia, is given as an example in Table 1 to reflect the nature of mechatronics curriculum [9]. The description of the course outline for the subjects stated in Table 1 can be found in [10].

Mechatronics curriculum in IIUM

The concept of mechatronics has improved the old approach of product design. That is, one would be required to design systems using combined knowledge of electronics, computer, mechanical devices, sensors and actuators, and controls so that the final design achieves the desired objectives. To achieve this, a mechatronics engineer would require a good balance of education and training in all the aforementioned disciplines. Consequently, an innovative mechatronics engineering program has been developed at IIUM, principally to provide a balanced curriculum that satisfies the integrated nature of mechatronics engineering. This is a four-year full-time program with its first intake in 1994. The main goals of this curriculum are briefly summarized below:

1. To develop a unique mechatronics curriculum that is compatible with the graduation requirements of the faculty of engineering, IIUM.
2. To expose students to a variety of subjects that would enable them to have sufficient knowledge of mechatronics engineering.
3. To delineate different options in mechatronics engineering thereby mapping students to their career needs and development.
4. To enhance students' analytical, practical and hands-on skills through selection of appropriate courses, laboratory experience and the available software tools and several semester projects.
5. To enable students to gain confidence and competence in planning, designing, and maintenance of integrated engineering systems.

Table 2 shows the list of courses offered to mechatronics students at IIUM. Courses marked with an asterisk require 1.5 hours of laboratory work per week. As observed from this table, mechatronics students can specialize in one of the following areas: *robotics and automation, intelligent machines, and real-time design*. This curriculum requires all the mechatronics students to take basic engineering and common mechatronics courses in the first, second, third and forth semesters of studies prior to selecting their fields of specialization. This approach will give students the right guidance and enough knowledge to select their core specialties as well as to broaden their knowledge in mechatronics as a whole. Based on this revised curriculum, specialization starts from the fifth semester or third year.

Courses for mechatronics students are selected to accommodate the needs of their particular field of specialization as well as to satisfy the faculty of engineering graduation requirements. The *general courses* are taken in the first year. These courses are common for all engineering students, mechatronics engineering students included. In the second year all mechatronics students would take courses that are *common for all areas of specialization within the area of mechatronics engineering* as shown in Fig. 1. Starting from the third year students would be required to take *courses in their areas of specialization*. The total number of credit hours per semester is fifteen out of which twelve credits are allocated for the core courses while the remaining three credits for an elective course. Taking into account another six credit

Table 1. Course outline for BE (Mechatronics Engineering) program in UWA

First Year	Second Year	Third Year	Fourth Year
Engineering, Computing, Mathematics, Physics.	Design and Manufacture, Machine Dynamics, Applied Thermodynamics, Computer Applications, Materials Engineering, Fluid Mechanics, Solid Mechanics and Mathematics.	Object Oriented Programming, Electronics, Electric Machines, Instrumentation Engineering, Risk and Probability in Engineering, Control and Mechatronics, Mechanisms with options in Robotics or Computer Vision.	Engineering and Society, A research or development project, Advanced mechanical/mechatronics engineering, Computer science, or electrical engineering topics chosen from a list of options.

Table 2. Course outline for BE (Mechatronics Engineering) program at IIUM (*ch* = credit-hour)

SEMESTER 1		SEMESTER 2	
Subjects	***c.h.***	***Subjects***	***c.h.***
Engineering Calculus I	3	Engineering Calculus II	3
Computing Systems and Programming*	3	Object Oriented Programming*	3
Electric Circuits*	3	Electronics*	3
Engineering Drawing*	2	Workshop Technology*	2
Statics*	2	Dynamics*	2
English for Academic Purpose	3	English required course English for Technical Communication.	3
SEMESTER 3		**SEMESTER 4**	
Subjects	***c.h.***	***Subjects***	***c.h.***
Signal and Systems*	3	Control Systems*	3
Digital Logic Design*	3	Theory of Machines*	3
Machine Design*	3	Microprocessors and Interfacing*	3
Electromechanical Systems*	3	Instrumentation and Measurement*	3
Linear Algebra	3	Numerical Methods	3
Bahasa Melayu	3	Bahasa Melayu	3
Management Course	3	IRKHS	3

Robotics and Automation		Intelligent Machines		Real-Time Design	
Courses	***c.h.***	***Courses***	***c.h.***	***Courses***	***c.h.***
SEMESTER 5					
Stochastic Processes	3	Stochastics Processes	3	Stochastics Processes	3
Power Electronics*	3	Micro-Electromechanical System*	3	Computer Architecture and Real-Operating Systems*	3
Digital Control*	3	Human-computer Interface (HCI)*	3	Applied Digital Signal Processing*	3
Management	3	Management Course	3	Management Course	3
Elective	3	Elective	3	Elective	3
Seminar	0	Seminar	0	Seminar	0
SEMESTER 6					
Semester Project I	3	Semester Project I	3	Semester Project I	3
Dependability	3	Sensor & Actuators*	3	Distributed Process*	3
Management Course	3	Management Course	3	Management Course	3
IRKH	3	IRKH	3	IRKH	3
Elective	3	Elective	3	Elective	3
Seminar	0	Seminar	0	Seminar	0
SEMESTER 7					
Semester Project II	3	Semester Project II	3	Semester Project II	3
Robotics*	3	Intelligent Systems*	3	Mechatronics System Design*	3
Modeling and Simulation for Dynamic Systems*	3	Machine Vision*	3	Microcontroller based design*	3
Management course	3	Management course	3	Management course	3
Elective	3	Elective	3	Elective	3
Seminar	0	Seminar	0	Seminar	0
SEMESTER 8					
Graduation Project	6	Graduation Project	6	Graduation Project	6
Elective	3	Elective	3	Elective	3
Elective	3	Elective	3	Elective	3
IRKH	3	IRKH	3	IRKH	3

LIST OF ELECTIVE COURSES Modern Control Design, System Dynamics, Mechanical Vibration, Special Topics in Mechatronics, Computer Integrated Manufacturing, Finite Element Analysis, Micro-manufacturing Technology, Tribology, CAD/CAM, Hydraulic & Pneumatics.

hours for the industrial training, the total credit hours required to complete graduation requirements is about 142. Here, one credit hour refers to one hour of lecture per week for a total of fourteen weeks that constitutes a semester.

The concept of the elective courses needs more elaboration. Elective courses for each of the three specialities are selected in such a way as to fill the gap between the specialization to a possible maximum extent. That means, students will offer in

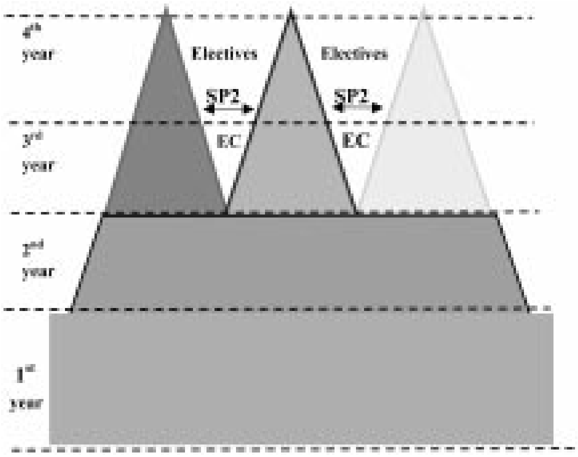

Fig. 1. Graphical representation of course outline for BE (Mechatronics) program at IIUM.

each semester (starting from third year) at least one elective course in addition to the core courses in their specialization. An important factor is that these elective courses are actually core courses for other specialization areas. Furthermore, students from all the three streams can choose more courses from the pool of elective courses shown in Table 2. Thus, students from one stream or specialization would have the option of selecting subjects from other specializations in accordance with their interests. Hence, together with the concept of semester projects this will create an optimal balance between the *minimum credit hours* and *maximum number of mechatronics subjects* and the students graduating form our university can easily fit into any of the three major fields of mechatronics.

The curriculum structure described above is shown in Fig. 1. In this diagram the time elapses from bottom up. The rectangle designates first year of common education for all students of the engineering faculty. The trapezoid falls on the second common year for the mechatronics students only. Each triangle indicates the group of students in a particular stream of mechatronics specialization at their third and fourth year studies. This time they take core courses, semester project one (SP1), and a graduation project (GP) specific to their specialization. Links between the specializations are denoted as an elective course (EC) while the semester project two (SP2) is indicated outside the triangles.

MECHATRONICS PROJECTS

Another important aspect of our curriculum is the introduction of the semester projects to be carried out within the program. That is, there are three projects to be completed before the students graduate. In this case, we have two semester projects (SP1 and SP2) and one final semester or graduation project (GP). The timing and content of these projects have been designed in the curriculum in such a way that they provide the best option for students to learn and practice their skills not only in the area of their selected specialization but in other areas of specialization as well. That means, a student has to take project SP1 at the sixth semester and select the title pertaining only to his particular area of specialization, whereas project SP2 would be taken in the following seventh semester with the title selected from any of the other two areas of specialization. The advantage of having two projects in two different areas of specialization enables the student to be well-trained and supervised in designing and handling of projects or physical systems. This approach will give the student a chance to compare different mechatronics systems as well as to look at diversified theories and techniques used to design and manage such systems. Finally, the student has to carry out the graduation project in his selected area in the last year of studies. All of this will enable the student to build an integrative way of thinking and perception about the design, implementation, monitoring, and maintaining of interdisciplinary mechatronics systems. Another advantage of the three projects is to enhance hands-on practice amongst the students. Each project should have elements of design, implementation, testing, and if possible, development of the prototype. This is what a mechatronics engineer needs in his future career after graduation.

A summary of typical projects carried in the department is briefly discussed below.

Robotics and automation

- Design and development of intelligent fire-fighting robot.
- Design and prototyping of SCARA-type robotic arm.
- Visual tracking and manipulation with robotic arm.
- Design of intelligent controller for a robotic gripper.
- Automatic storage and retrieval system.

Intelligent systems and real-time control

- Automatic sunlight protection for a car.
- Internet based robotic arm control.
- Internet-based pump control.
- Design and prototyping of intelligent dish washing machine.
- Intelligent auto focusing.
- Automatic fault detection in rotational machinery.

One can easily see from the above project titles that the mechatronics students have great opportunities to put the knowledge gained from the subjects into practice. For example, design of the fire-fighting robot requires an integration of appropriate sensor and microcontroller technologies along with the ability of students to develop and implement the strategies to navigate the robot towards the fire.

Fig. 2. Setup for automatic fault detection system.

Another project on visual tracking and manipulation implies an intelligent robot that can track the objects with a single camera and perform necessary manipulation. The knowledge of hardware, software and machine vision has been used in the design and implementation of these projects. Figure 2 depicts the setup for the project for detecting vibration fault signals in a rotating machine. This involves the designing of a test rig with supervisory software, which can automatically determine the type of fault using spectral analysis techniques. In general, all the projects assigned to the students should require the integration of knowledge from the variety of subjects taken by the students.

POSTGRADUATE PROGRAM

IIUM has also been running postgraduate programs in mechatronics since the beginning of its undergraduate program. A graduate student has to take eighteen credit-hours coursework and eighteen credit-hours research. For admission purposes, students with a bachelor degree in mechatronics are the main target at this stage, however mechanical and electrical engineers with good background in appropriate areas of mechatronics can also apply. The courses taught at the graduate level are shown in Table 3.

Research topics are generally selected in the following areas:

- Intelligent control system design.
- Robotics and control.
- Active vibration control and smart structures.
- Machine vision.
- Digital signal processing.

One of the representative masters thesis in the area of intelligent control system design is reported in [11]. In this research work a neuro-fuzzy algorithm has been implemented through a digital signal processor for the control of automobile brake systems.

TEACHING STAFF AND LABORATORY FACILITIES

It is well known that a well-designed curriculum alone cannot help produce good graduates unless there are good teaching staff and laboratory facilities. Presently, it is very difficult to find lecturers with mechatronics background, hence lecturers having backgrounds in related mechatronics disciplines are specifically recruited under the mechatronics engineering department to teach their respective disciplines within a mechatronics program.

Integration of knowledge is also applicable in the case of setting up laboratories and experiments. Mechatronics systems design, robotics, digital signal processing laboratories are good examples of such integration. The mechatronics engineering program is supported by instrumentation and measurement, control, computer integrated manufacturing, robotics and automation, mechatronics systems design, applied mechanics, microprocessor, digital logic design, software engineering,

Table 3. List of graduate courses

Advanced mechanical vibration	Real-time System Integration
Microprocessors in Mechanical systems	Neural Networks and systems
Advanced Control System	Structural Dynamics and Control
Intelligent Machines	Advanced digital signal processing
Advanced Topics in Robotics	Computer vision and image processing
Digital Control System Design	Real-time computing systems
System Dynamics	Sensing and modeling in Manufacturing
Advanced Topics in Mechatronics	Advanced microelectronics circuits

electronics and electric circuits laboratories at IIUM. All these laboratories are equipped with up-to-date instruments, software, hardware and other necessary facilities.

FUTURE DEVELOPMENTS

As expected of any engineering program, there would be the need to review the mechatronics program here to make it respond to not only the Malaysian industry but also the state-of-the-art technology. In addition, more academic staff and laboratory facilities would be needed to support the existing staff, especially with the commencement of automotive and aerospace engineering programs in the faculty. The department is also planning to have mechatronics workshop for the students at the introductory levels as well as machine vision and precision engineering laboratories for both senior level and graduate students. At present the engineering faculty and the Malaysian Centre of Robotics and Industrial Automation (MCRIA) have jointly developed the robotics and automation laboratory for teaching and research activities. It is our plan to extend this type of collaborative activity to other related industries in Malaysia. Furthermore, the departmental proposal for a mechatronics chair in intelligent engineering systems is seriously under review.

CONCLUSION

The gradual change in the industry has urged the need to review the engineering education and training so that graduate engineers can become very relevant to industry. Curricula and courses that have been designed and implemented to meet this objective are discussed in this paper. Unlike the mechatronics curriculum in other universities, IIUM has three different streams of specialization for the undergraduate mechatronics program. Moreover the overall design of the curriculum is such that even a graduate specialized in any one of the streams can also work in the others.

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