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Postgraduate and undergraduate mechatronics' courses at the University of Wollongong

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Abstract

This paper outlines the University's involvement with Industry based manufacturing projects, and how this has lead to the recent establishment of postgraduate and undergraduate Mechatronics degrees. The nature of the industrial projects will be described with examples of specific problems, test equipment and experimental rigs given. This work will be used to explain the reasons for the design of the mechatronics courses at Wollongong. A new teaching methodology particularly suitable for mechatronc's education is also discussed.

Index Terms: Mechatronics, Education, Web- based learning

I. INTRODUCTION

Mechatronics courses are being increasingly introduced in Universities around the world. These courses attempt to reflect the needs of modern Industry, as changing technology now requires graduates to have skills which cross the boundaries of classical engineering disciplines such as electrical and mechanical engineering. In particular the term mechatronics engineering attempts to capture the idea of multi-skilling across several areas such as electrical, electronic, mechanical, materials, and computer engineering and other disciplines. Being relatively new, mechatronics engineering courses have been implemented in many different ways in Universities across the world, and there is no widespread agreement about the 'best' way. This paper describes the history of mechatronics industrial project work and teaching developments at the University of Wollongong. It includes reference to details of the content of recently established mechatronics courses at both undergraduate and postgraduate levels.

II. INDUSTRIAL MECHATRONICS PROJECT WORK

The University of Wollongong has traditionally paid a lot of attention to working closely with Industry via research and development projects funded both by Industry and Government. Academics in Australia are typically expected to devote about half their time to research work, with their remaining time being devoted nominally to teaching. This system works well in engineering when a number of staff combine in a sufficiently narrow area to be able to deliver quality results within defined delivery times. The resultant attraction of substantial Industry and Government funding has allowed the building and operation of the expensive infrastructure and equipment required to do such work. It also provides relevant experience to enable staff to have a high level of expertise, and sets up exactly the right environment needed for teaching in the area.

Four recent examples of typical projects which influenced mechatronics skills at Wollongong are described in the following. Funding for these projects has been via joint Industry-Government agreements

The first example is the development of ways to automatically drill holes in large scale work pieces, such as ailerons for aircraft. The project concentrates on the design and operation of a robot system able to be quickly located at different large scale work-pieces, whilst still being able to perform very accurate drilling and other related operations. The intention is to provide greater flexibility, shorter set-up times, and more cost-effective, higher quality production of small batches. A particular feature of this project, and one which has generic interest in manufacturing, is the problem of achieving 'large scale' movements of a multipurpose manipulator whilst still achieving high accuracy. It is necessary to achieve a hole centre accuracy of 20 microns over a workpiece area of about 8 metres by 2 metres.

Three fundamental components of a flexible system are being developed, with working prototypes being constructed. The first consists of a large scale manipulator which can move along the vicinity of the long axis of a large structure. The second component, the gripper and tooling system, attached to the large scale manipulator will move along at least the vertical axis. A tool attached to the gripper, with up to two rotational axes and one translational axis of movement, is able to achieve operations, such as drilling, along an axis normal to the structure's variable curvature at any point on the structure. The whole system is controlled by a computer control system with a substantial amount of new software being required.

One of many issues being resolved by design and prototype testing is that of the cost/accuracy trade-off. A commercial robot fixed solidly to one site can achieve repeatability

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typically of about 100 microns in the absence of reaction forces from the gripper. Finer motion incorporated into the gripper, and clamping while drilling has shown that repeatability to about 10 microns is achievable at reasonable cost, even taking into account the drilling forces.

This project clearly is a collection of challenging mechatronics projects, with every sub component requiring expert mechanical, electrical and computer design, and with many sensing and processing problems. The final result will require trade-offs involving not only technical considerations, but also cost, reliability, safety and operator user friendliness. Such a project also gives rise to a number of mini-projects suitable for undergraduate students. Such students can work on refining the various complementary subsystems, with negligible incremental cost to the University, and in such a way that their project cannot slow down or affect the project's commercial outcomes.

The second project is intended to improve the performance of grinding machines by finding new high speed real time intelligent adaptive controls. Modern digital control of servos provides the potential for faster and cleverer control to be implemented to enhance performance. Such control requires an understanding of factors affecting the drive train and actuator, such as friction, backlash and cogging, and also a better understanding of the process, such as grinding. This understanding enables more accurate mathematical models to be developed so that improved control strategies and algorithms can be deduced. Implementation of such algorithms requires sensing of relevant variables, such as accelerations, grinding forces and torques, surface conditions, etc.

Work on this project so far involves the development of new techniques for identification and control of static friction, and their implementation on practical machines. These have been used successfully to demonstrate a performance improvement at least at the sampling instants. Many other friction parameters as well as other effects giving rise to torque pulsations such as cogging, belt teeth and pulley torques have also been identified and modelled.

Additional research in modelling and sensing of the grinding process is necessary because virtually all grinding machines at present rely only on position and velocity control, with negligible feedback from the actual grinding process. So far this project has shown that the use of acoustic emission and force sensors can be used to provide information about the grinding process, including parts finish and wheel condition.

The third project discussed here also concentrates on improving CNC machine performance by researching the computer control and mechanical design of actuators, bearings and drive trains.

In particular, new motors, such as linear motors are becoming increasingly competitive so that with appropriate bearings and controls they have the potential to remove some of the current barriers to improved actuator performance. Research has been conducted to investigate and quantitatively benchmark the performance of these alternative motors. Of particular interest is their low and high speed performance, their torque and power to weight ratios, their ability to be controllable in real time, their impact on the cost and performance of currently available electronic drives, the size of torque pulsations introduced by cogging, and their ability to reject torque perturbations.

The fourth project discussed here is one of many in the arc welding area. Arc welding also nicely demonstrates the need for mechatronics, because many issues involving weld quality and arc control consist of both electrical problems (high speed computer control over current, voltage and wave-shape), and mechanical and materials engineering and physics problems (jigs, fixtures, accurate wire feeding, conditions in the arc, steel and alloy metallurgy)

This project concentrates on finding ways of reducing spatter in gas metal arc welding (GMAW) in carbon dioxide. The idea is to control the shape and magnitude of the current during the short circuit period of the process. This has required a mathematical model of the process to be developed and the design of very high performance power supplies controlled by high speed computers in an effort to provide the necessary control.

These and other industrial projects have given rise to significant mechatronics infrastructure in our laboratories most of which is also available to assist student projects. This includes:

- Development of a fully instrumented high performance precision X-Y test-bed representing current state-of-the-art machine tool design (approx 1 micron position accuracy)
- many high speed digital signal processor based controllers for general actuator control, available for student projects
- a variety of accelerometer, acoustic emission , multi-axis force and torque sensing systems for machines
- a cylindrical grinding test-bed with two servo controlled axes
- many actuators (permanent magnet, reluctance, AC & DC servos, linear motors) and a variety of drive trains set up as instrumented test beds.
- several five axis articulated and SCARA robots
- considerable welding equipment with associated instrumented and DSP controlled power supplies.

Of course, one of the main benefits of this sort of work as far as students are concerned is the development of state-of-the-art expertise within the teaching staff. Since nearly all of this work is industrially funded, it also means that academic staff are very aware of what Industry needs from its graduates, and this experience is built into the structure of the mechatronics course and into the design of the individual mechatronics subjects.

III. Development of Undergraduate and Postgraduate Mechatronics Degrees

The industrial work of the sort described above emphasized the need for courses in Mechatronics, an integration of electrical, computer, and mechanical engineering. Postgraduate mechatronic degree programs were introduced in 1996 to cater for students with either a Mechanical Engineering or Electrical Engineering background, and in 2000 an undergraduate mechatronics degree was introduced.

At postgraduate level we are in the position of having to cope with training graduates from electrical and mechanical backgrounds, because there are as yet relatively few graduates in mechatronic degrees. Hence two one year full-time course work postgraduate degrees were offered. One, primarily for electrical engineering graduates, is called the Master of Engineering Studies, and the other, for mechanical engineering graduates, the Master of Engineering Practice. These degrees essentially provide the 'missing' computer and electronic engineering skills to mechanical engineers, and mechanical theory and design skills to electrical engineers. There is also considerable laboratory and project work in both degrees where students work on practical industrial automation projects, usually derived from our research and development projects.

Unfortunately, the nature of these degrees, the pre-existing training of entrants, and constraints on resources meant that only some of our ideal requirements for mechatronic education could be implemented at this level. However, it is at the undergraduate level where, given a 'clean slate', we were able to implement the full range of education we believe is desirable for this discipline.

The industrial research work described in Section 1 above demonstrated the importance of an integrated approach to Mechatronics. It is this approach which gave rise to the field of Mechatronics in the first place and was seen as the focus point for the design of the curriculum. It was felt that many existing Mechatronics undergraduate courses tend to be conventional mechanical engineering degrees with a few, too superficially treated, electrical engineering subjects added. However we felt that greater depth in electronics, embedded computing and programming is required for graduates to successfully design mechatronics systems. In particular we placed considerable emphasis on having subjects with computer science, real-time computing and electrical engineering skills in the mechatronics curriculum, as well as the more traditional mechanical engineering and machine design skills.

There is also an emphasis on embedding team building and management training into project-based subjects in the degree, and advanced simulation and computer assisted learning is used to complement (as opposed to replacing) aspects of the course such as control theory and laboratories, which students commonly find difficult. To give an example of this, details of how the control engineering subject is structured will also be described in Section IV.

The following gives an overview of the premises for development of the Mechatronics curriculum at the University of Wollongong:

1. All the fundamental electrical and mechanical engineering and computer science subjects should be included in the course. Table 1 gives an overview of the developed course. It shows that Engineering Science related subjects account for 16% and Engineering Fundamentals account for 41% of the course.
2. The philosophy of engineering design should form an integral part of the curriculum. It was felt that this should be taught throughout the course, from first year up to final year. About 12% of the course can be classified as formal design subjects, although most other subjects of the course include some elements of design.
3. Mechatronics is an interdisciplinary field and because of this it is even more important than for the more traditional fields of engineering that graduates can interact successfully with people from other disciplines, and understand fundamental aspects of business such as costing, quality control, team building and project management. Such training is an important aspect of the curriculum and should not only be done at an abstract level in management subjects but complemented by a significant amount of practical project work throughout the curriculum. About 15% of the course can be classified as this type of training. These skills are then applied in the various projects and laboratories of other subjects.
4. The degree should include a substantial Mechatronics project in which students can apply the skills acquired throughout the course. This is done in the final year of the course in the subject "Thesis". In this subject, the student has to individually solve a relevant Mechatronics engineering problem, usually in the form of a design or research project. These projects are often related to industrial projects of members the academic staff. This gives the student the opportunity to experience real life mechatronics engineering problems in an industrial environment. The student is normally supervised by a member of the academic staff and if appropriate, by an employee of the industrial partner. Apart from the technical aspects, the student is confronted with project management, team and leadership skills and economics. The project includes oral presentations and various written reports.
5. The last year of the course allows the student to further specialise in a certain area of Mechatronics by giving the option of a selected group of electives. These electives can be taken in the area of control and automation, robotics and

manufacturing and programming and computer applications.

	1st Year	2nd Year	3rd Year	4th Year
Engineering Science, 16%	Computer Science 1A Mathematics 1A-1 Mathematics 1A-2 Fundamentals of Physics B	Mathematics IIe Computer Science 1B		
Electrical Engineering Fundamentals, 25%	Electrical Engineering 1	Digital Hardware 1 Circuits and Systems Electronics and Communications	Control Theory Electronics 3 Digital Signal Processing Digital Hardware 2	
Mechanical Engineering Fundamentals, 16%	Engineering Mechanics	Mechanics of Solids Engineering Materials	Manufacturing Engineering Principles Machine Dynamics	
Design, 12%	Introduction to Design and Innovation	Fundamentals of Machine Component Design	Mechanical Engineering Design Mechatronics Design	
Management, Team work, Economics, 15%	Professional Engineers and the Management of Technology			Project Management and Human Factors Professional Experience Thesis
Specialisation, 16				Mechatronics Electives Thesis

Table 1: Overview of Bachelor of Engineering (Mechatronics) at the University of Wollongong

Obviously when combining the curricula of electrical engineering and mechanical engineering and adding mechatronics specific subjects, some areas could not be covered by traditional mechanical or electrical engineering subjects – there is just not enough time available. These included power electronics, thermodynamics and fluid dynamics. It was felt however that these areas should be included in the course, although with less depth than is currently done for the electrical or mechanical engineers. They were combined in one new subject

One of the benefits that came about because of the undergraduate Mechatronics course was significantly improved interaction of staff between the disciplines. Subjects are taught together, laboratories are shared, projects and thesis students are supervised together and in a number of cases collaborative industrial research was initiated. However, it was also recognised that some staff might have felt "left out" of this development. This is something to be aware of when Mechatronics programs are being considered and the effect can be minimised by keeping as many staff as possible involved in the teaching of the course.

The program has now run for two years with 14 enrolments during the first year and 29 new enrolments during the second year. This is about 80% of the Mechanical Engineering and about 40% of the Electrical Engineering undergraduate enrolment of the University of Wollongong. It is expected that this enrolment will further increase over the next few years. Articulation programs have recently been developed for the various TAFE (diploma) courses in Mechanical and Electrical Engineering in Australia as well as for diploma students from Vietnam, China, Malaysia and Singapore. Such students are given about one to two years of advanced standing for these programs, depending on their past performance.

IV. Computer and Web-based Flexible Delivery

With the rapid development and advancement of Information Technology, radical changes are taking place in the delivery of teaching and learning resources at tertiary level. For example, the web allows resources on the subject matter to be delivered anywhere and anytime. In engineering and science education, this is recognised as a positive step towards a more flexible and more effective teaching and learning environment at a potentially much lower cost.

The new educational delivery tools such as the world wide web can also enhance the interaction between students and instructors. Off-line and on-line interactions are established between students and lecturers as well as among students themselves. Such an environment is commonly referred to in the literature as a "virtual classroom".

Currently, the majority of educational Web sites lack interactivity [1] and instructional approach. They mainly act as an alternative method of providing information and educational resources to textbooks, handouts, etc. For example in [2], the developed computer-aided learning package is only a hypertext on the computer with links to the available resources.

The more advanced Web sites also provide a channel of communication between the students and staff for the electronic submission of tutorials and assignments or receiving feedback. An example is the work developed at the University of Illinois at Urbana Champaign (UIUC) [3] in which problems in Circuit theory are provided on line and students submit their answers using file transfer protocol (FTP). Another example is the work conducted by Carver et al [4] in which a Web-based platform for the delivery of an interactive tutorial and simulation package is developed.

There are also a few research groups who are studying the potential of the concept of a student centred Web site but no development has yet taken place. A good example is the Cornell Theory Centre [5] which has been investigating the use of emerging network technologies for training scientists in the concepts of parallel processing.

The Web-Based Instruction is defined by Khan [6] as "... a hypermedia-based instructional program which utilises the attributes and resources of the World Wide Web to create a meaningful learning environment where learning is fostered and supported." Currently a Web-based instructional system is capable of accessing all the services available on the

Internet, exhibit all types of media, and execute embedded or external software.

Because engineering subjects contain codified knowledge and algorithmic skills educational computer simulation programs and computer-aided learning modules have been employed to further promote the well-known approaches of problem-based and project-based learning. Generally, the new and emerging educational tools and methods offer a strong potential to increase learning productivity in such areas.

The subject Control Systems, an important area of mechatronics, is discussed here as a case study and extensive computer-based and Web-based instructional materials have been developed for it [7 ,8 , 9].

The pedagogical model employed in the development of the computer-based and web-based instructional systems has been the Cognitive Apprenticeship model [10,11] which incorporates the key elements of vocational education into academic learning. This concept describes the relationship between the master (lecture/tutor) and his/her apprentices (students). The term apprenticeship also calls in mind the notion of "hands on" learning which not only includes learning the theory but developing the skills needed to utilise the theory. Two major computer based components have been developed: A/ Computer Assisted Instruction and B/ Computer Assisted Laboratories.

A Computer Assisted Instruction System for Teaching Control

An interactive computer assisted instruction system, referred to as Computer-assisted Instruction System for Control (CISC), has been developed. The CISC uses simulation and animation extensively to illustrate a problem and to highlight the effectiveness of the obtained solution.

The contents of CISC are broken down into a number of chapters. Each chapter covers a major topic in the control theory such as "root locus" or "frequency response analysis". Each chapter consists of three major modules:

(a) **Overview** - In this section the significance of the topics are illustrated, an overview of the subject is given, and some theoretical aspects of the topic are covered. An overview frame describing open loop control system in the "Introduction Chapter" is illustrated in Figure 1.

(b) **Examples** - The aim of this section is to enhance the students' understanding of the theory through a series of examples. The examples are carefully chosen to emphasise the important points covered in the *overview.* Animation is used extensively to make the problems and solutions provided as tangible as possible

(c) **Tutorial** - This is another module incorporated in each chapter to enhance further the understanding of the students and master them in the topic. The *tutorial* itself is further subdivided into *workshop, multiple choice questions* and *problems*.

(i) In *workshop* the student is tutored to solve a problem related to the topic. This section is fully interactive. A *workshop frame* is illustrated in Figure 4. In this frame students are requested to develop the block diagram representing the control system of a toaster. The procedure consists of moving one of the blocks on the right hand side to a position on the block diagram.

(ii) Multiple choice questions are provided to allow students to find out their progress for themselves.

(iii) The *problems* section provides additional problems with answers. The aim is to enhance the skills and confidence of the student in tackling the problems.

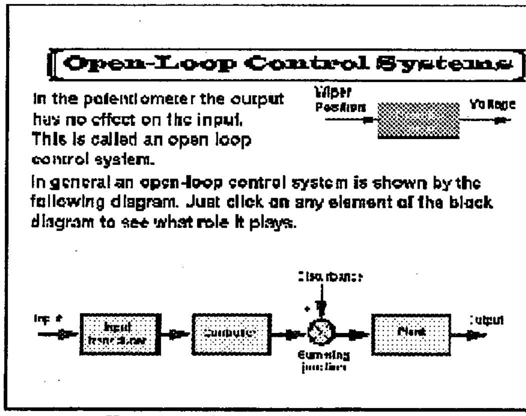

Figure 1 - A typical overview frame

A user can move from one frame forward or backward, branch to various modules of a chapter, and also transfer to the main menu to start new chapters. A typical overview frame is illustrated in Figure 1.

B Computer Assisted Laboratory Instruction

Individualised instruction becomes more crucial in a practical laboratory. The students require constant attention to ensure that correct procedures are followed and instruments are employed safely. In addition the validity of the results obtained should be also continuously monitored to guarantee that the experimental rig is set up technically correctly and appropriate methodologies are applied.

The laboratory section of the course consists of various analysis and design experiments based on a DC servo motor with tacho feedback. In order to overcome the problems referred to above in running the laboratory component of the control subject, a computer assisted laboratory instruction (CALI) system has been developed. The CALI system has both analogue and digital control components.

The CALI package is delivered on the World Wide Web (WWW), in which students can master background knowledge, practice some operational skills, and learn troubleshooting methods independently from the timetabled sessions.

The instructions are structured hierarchically. The overall content is delivered through 5 major nodes of Laboratory Overview, Laboratory Equipment, Project Description, Project Procedures and Report and Assessment.

The following instructional strategies are employed in the CALI system:

- *Tutoring:* For each step of the experiment, the tutor system provides sufficient information on "what, when, why and how", in relationship to any particular topic.
- *Simulation:* Computer simulations are provided for critical tasks such as selection of the equipment or connecting up a particular circuit.
- *Troubleshooting:* The potential problems are pointed out to students for any particular experiments and possible solutions presented through comprehensive text, graphics or animation.
- *Search Engine:* A search engine is provided to assist students to search for key words using different logic relations such as "AND" and "OR".
- *Frequently Asked Questions (FAQ) &Help (Forum):* A forum is used for posting FAQ and helps. Any student is able to post his/her questions to the forum.

V. Conclusions

The development of Mechatronics education at Wollongong University has been driven by practical experience with many Industrial Automation and mechatronics projects regularly undertaken by academic staff. This experience, apart from providing students with access to appropriate equipment and infrastructure, has lead to the development of a mechatronics curriculum with strong electrical, computer and mechanical engineering and computer science components. In addition attention is paid at all stages of the undergraduate course to the development and practice of business and team building skills by the students. Details are also provided to show how web based education can be exploited to benefit mechatronics teaching, and it is expected that this methodology will play an increasing role in mechatronics and other education in the future.

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