THE EVOLUTION OF MECHANICAL ENGINEERING CURRICULA: MECHATRONICS

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***Abstract** - This paper discusses one area in the ongoing evolution of Mechanical Engineering curricula, Mechatronics. Mechatronic devices are widespread – CD players, cars, autowashers, robots, disc drives, photocopiers etc. – mechanical devices which involve a microprocessor, electronics and control. The evolution of the classical Mechanical Engineering degree into a separate degree in Mechatronics is fully in keeping with the desire for a high-tech, knowledge-based economy. The philosophy and the rise of Mechatronics-related teaching is briefly reviewed and the possible diversity of courses indicated. Two case studies are presented. The first describes the experiences of two of the authors in developing a Mechatronics undergraduate degree programme when they were at the University of Auckland, the motivation behind the decision and the structure of the course. The second case study is a proposal for a multi-media based course in mechatronics which could be utilised for a European-wide degree.*

Index Terms - Mechatronics, complex decision making, synthesis of engineering systems, education.

INTRODUCTION

The problems being faced by engineers are increasingly interdisciplinary and complicated because the development of new (often extremely complex) products and processes depends upon the integration of many different technologies.

Until perhaps 10 years ago, the engineering industry was often organised by disciplines (and in many places throughout the world still is) electrical, mechanical, etc. However, due to the need to provide a more interactive design environment in the development of modern products, it is recognised that this approach makes it extremely difficult to provide the best design solutions to the engineering problems posed. Mechatronics inherently reflects this trend, but also manages to take the ideas of interaction further, that is from multi-disciplinary team approaches towards multi-disciplinary thinking by individual engineers. Tomizuka [1] goes further than this by stating that “Mechatronics may be interpreted as the best practice for the synthesis of engineering systems”.

Compared to Systems Engineering, Mechatronics is generally a more low-level discipline in the sense that there is a stronger emphasis upon the technology being produced and less upon the process, which is usually central to systems engineering. A mechatronics engineer inevitably deals with the technology because the subject enforces (or at least encourages) cross-disciplinary thinking and design in a manner which is more accessible at a working level. Mechatronics is also important at a component level, enabling innovative solutions, which can add significantly to the overall solution [2]. It is extremely important that young engineers are educated so as to be comfortable working in, and across, many different domains.

It is also instructive to consider the relationship between Control and Mechatronics. It can be argued that practical control engineers were already mechatronics engineers at the time the word was invented because control engineering implicitly considers the interaction between the “electronic controller and the mechanics” at the design stage. This is perhaps reflected in the make-up of the authors for this paper. Two of them initially trained as control engineers while the third became actively involved in the real-time computer control of structural vibration as part of his research activities.

This paper emphasises the importance of Mechatronics in engineering design. The industrial requirements for design engineers who can think both within and across different disciplines has already been indicated in the introduction. Mechatronics is then defined and the continuing evolution of the area indicated. Academic issues regarding the generation of engineering graduates in Mechatronics are then considered. Many of these issues are addressed in the first case study, which concerns the development of a Mechatronic Engineering degree at Auckland University. The second case study highlights the diversity of courses that could be termed ‘mechatronic’ as well as proposing a European-wide degree in the subject area.

MECHATRONICS

The term ‘Mechatronics’ was introduced in the late 1960s by Japan’s Yaskawa Electric Company and was derived from the synergistic combination of mechanical and electrical/electronic technologies [3]. The definition currently adopted by the IEEE/ASME Transactions on Mechatronics is the following [4]: “Mechatronics is the

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synergistic integration of Mechanical Engineering with electronic and intelligent computer control in the design and manufacture of industrial products and processes".

Mechatronic devices are widespread – CD players, cars, autowashers, robots, disc drives, photocopiers etc. – usually mechanical devices which involve a microprocessor, electronics or control. Mechatronics is still evolving though, from being simply the interaction between electronics, control and mechanical systems to the incorporation of microprocessors, and then complex decision-making via the incorporation of elements such as fault detection, adaptive control and soft computing. In particular, recent advances in communications such as the internet and wireless communication have enlarged the range of mechatronic components from unit devices to large-scale distributed systems. Tomizuka [1] provided a 'Y2K' definition of Mechatronics as "The synergistic integration of physical systems with information technology and complex-decision making in the design, manufacture and operation of industrial products and process". This makes more explicit the interdisciplinary decision making required of a mechatronics engineer, as well as recognising the increasingly significant role that information technology (IT) will play in Mechatronics.

A COURSE IN MECHATRONICS

Despite the desirability of mechatronics engineers in industry, in academia the main consideration will usually be 'can we attract more students to the department'? In fact for the first case study, the introduction of a Mechatronics degree at Auckland University, student surveys indicating the likely recruiting success of such a degree provided the main, if not the only, motivation for the department accepting the degree proposal.

The current boom in interest in information technology by students has created student recruitment pressures for many engineering departments. A similar scenario encountered by one of the authors at three different academic institutions is the inability of departments to recruit students who have an engineering bias but don't see as much IT content in the courses as they would like. These students often end up choosing Computer Science courses. Some of this can be attributed to engineering departments either being slow or totally unwilling to diversify, or simply to poor presentation. Choosing an appropriate name for a degree programme to emphasise both the engineering and IT content is sometimes all that is needed to improve recruitment. For example, the Electrical and Electronic Engineering Department at Auckland University was extremely quick off the mark to develop new courses with simple and effective 'titles' that implied the integration of electrical engineering and IT, such as 'Software Engineering' and 'Computer Systems Engineering'. They subsequently obtained large student intakes because of it.

The second case study was motivated mainly from research considerations, i.e. to produce graduate engineers better equipped to do research work in a very specific area of Mechatronics: smart structures.

COURSE REQUIREMENTS

Mechatronics papers, courses and degrees *per se* originated over 30 years ago and now proliferate around the world. Mechatronics has become an internationally recognised discipline and mechatronic engineers are very employable. The first course was run in Europe and then in the USA and Japan. In the traditional engineering courses, the emphasis is on knowledge, technical and analytical aspects. On the other hand, a Mechatronics degree:

- requires an integrated interdisciplinary approach;
- emphasises design and implementation through effective communication and teamwork.

Through a Mechatronics course, students should experience from the outset the 'real world' demands of designing and manufacturing products to match customer requirements. Craig [5] states:"In Mechatronics, balance is paramount. The essential characteristic of a mechatronics engineer and the key to success in Mechatronics is a *balance* between two skills:

- Modelling (physical and mathematical), analysis (closed form and numerical simulation), and control design (analogue and digital) of dynamic physical systems.
- Experimental validation of models and analysis (for computer simulation without experimental verification is at best questionable and at worst useless) and understanding the key issues in hardware implementation of designs".

To reflect this and to encourage closer ties with industry, it would be extremely desirable that students undertake industry-based projects as an integral part of the course curriculum.

Human Resources

For any course to be successful, the academic institution would need highly motivated staff. However, the task of finding suitably qualified staff to teach Mechatronics has it's own challenges. This is due to the following:

- Mechatronics being a relatively recent stream of engineering, there are not many mature academics with suitable qualification in Mechatronics.
- Mechatronics is a rapidly progressive field of engineering. Therefore, academic staff have to be engaged in Mechatronics-related research to keep their knowledge current.
- The industrial demand for mechatronics engineers means that they are very well paid when compared to

academic salaries. Not surprisingly, many choose the industry especially as an academic career these days is characterised by increasingly long hours and the stress that goes with it.

It has been suggested [1] that in Mechanical Engineering departments, academic staff members specialising in control and design must act as leaders to bring Mechatronics into the engineering curriculum. This usually happens naturally, driven by the interactive nature of their disciplines and also the understanding that the current structure and content of classical Mechanical Engineering degrees does not adequately prepare graduates for a career in industrial design.

Laboratory Facilities

Mechatronics is a practically orientated field of Engineering. Students need to experience, in practical terms, the effect of a Mechatronics approach to holistic design of a product. Appropriate laboratory facilities are therefore mandatory.

CASE 1: AUCKLAND UNIVERSITY

New Zealand is a country of 3.6 million people located in the South Pacific with a landmass approximately the same size as Great Britain or Japan. It is basically a farming country, with additional major industries being timber and tourism. It currently does not have what can be described as a burgeoning manufacturing industry though there has been much growth, in the last 5-10 years, of small, specialised, high technology firms. It is these firms that will mainly employ graduates of the new degree, helping to increase growth in this area.

As a small country New Zealand cannot compete financially with many basic industries abroad. For instance, in the last few years the financial folly of having a home-grown car production facility was recognised. It was also recognised that New Zealand should be aiming to distinguish itself in ‘Pacific Rim’ markets and beyond with high-value innovative products. Currently, in farming, it tries to do this with products such as ZESPRI (a new name for Kiwi fruit) and venison (i.e. deer farms). Where it fails to do this is in the timber industry, where much of the timber is just de-barked and then sent overseas for value to be added to the product. In the high tech world, however, there are a number of successes: a whiteware and healthcare manufacturer, Fisher and Paykel, pride themselves on their innovative products and export extensively to Australia and beyond.

Two of the authors proposed [6] that a new, four-year B.E. degree in Mechatronics be established at the University of Auckland. This degree would be in addition to the traditional B.E. degree in Mechanical Engineering (ME). The intention was that Mechatronic degree graduates would be engineers with a broad-based education in Mechanical Engineering but with some specialisation in the areas of mechanics, dynamics, control, transducers, computers, microprocessors, electronics and their interfacing.

A number of meetings with staff in the faculty and reactions to the initial draft of the proposal made us realise the extent to which we would have to *sell* the idea. There have been Mechatronics ‘elements’ in the Mechanical Engineering degree at Auckland University for many years. However, these were accommodated in the existing degree course by the addition of elective papers and projects in Part IV, and in the design papers. Basic questions raised in reaction to the initial draft proposal included ‘Why a Mechatronics degree? Why not more electives as part of the current degree? Why now?' The answers to these questions, we felt, lay within the School of Engineering at Auckland University (regarding academic, administrative and financial issues and constraints); with the qualities and abilities of the graduates we would like to produce; with demands from the students themselves; with the needs of New Zealand industry and the Profession.

Academic Issues

The current Mechanical Engineering degree is a four year degree. The students can only specialise by their choices of Part IV electives and project. We argued that specialisation must begin earlier than Part IV because of the quantity of material, especially pre-requisite material, that is involved. For example, it is essential that students understand the principles behind the operation of a microprocessor before they can attempt a mechatronic-based final year project. Thus, we felt that major restructuring of the existing Mechanical Engineering degree would be required in any event, while introduction of a new Mechatronics-orientated degree would seem straightforward by comparison.

Another consideration that had to be taken into account is that of engineering student numbers. We felt that having a clearly identifiable Mechatronics degree would attract more and different students than would be the case were additional electives included in the Mechanical Engineering degree. It was obvious that a new degree in Mechatronics would attract some students who would otherwise take Mechanical Engineering, Electrical/Electronic Engineering or some other engineering degree. There were also indications that there would be a strong international market for the degree: overseas students would come to Auckland especially to do the Mechatronics degree instead of going, perhaps, to other Pacific Rim countries. We emphasised to the department the need to think globally, especially when we could offer an internationally recognised qualification from a university with a strong international reputation, at a cost that is substantially less than in most other countries.

Where student numbers are concerned, we argued that one option would be to allow market forces (i.e. student demand) to determine the maximum enrolment. Surveys indicated a very strong potential demand. This is natural enough, since this is an exciting and highly relevant subject. The potential for increased student enrolment was very high.

Industrial Issues

The main motivation behind the proposal was the belief that producing mechatronics engineers would be beneficial for New Zealand's industry. Industrial company surveys reinforced this belief.

Another reason behind the proposal was born out of frustration. There is a strong tendency in New Zealand industry to employ electrical engineers where control design and implementation, the programming of microcontrollers etc. is required. We wanted to challenge this perception because we believe that when NZ industry ignores control-orientated Mechanical Engineering graduates it is usually rejecting the person most qualified for the job. Indeed, in New Zealand the image of Mechanical Engineering is often the old-fashioned one: the design of stiff, static structures, pressure vessels, heat exchangers etc. The new degree will hopefully change this situation. This is somewhat in contrast to overseas practise, especially in countries where there are significant motor vehicle or aerospace industries, where mechanical and electrical engineers tend to be viewed as equal partners when it came to control engineering functions. The Mechanical Engineering Department has in the past perpetuated this attitude with poorly qualified staff teaching control. The department, as recently as 1993, employed it's first Control lecturer with a Control background, i.e. a PhD in Control Engineering.

It is inevitable that there will be very rapid developments in this field of engineering: the broad base of education we proposed was motivated by the need to produce flexible, adaptable, educated graduate engineers.

Finally, we argued in the proposal that the broad base of the proposed degree is necessary to produce graduates who are versatile and employable in a wide range of situations. One characteristic of New Zealand is the diverse nature of engineering: we knew that we had to accommodate that consideration.

At Auckland, we proposed teaching Mechatronics within a more general engineering framework, which follows somewhat the lines of many American universities. These place emphasis on project-related aspects, which we believe are essential for good quality graduates. While this is potentially costly in terms of financial and academic input, we believe it is essential to the quality of our graduates.

Course Structure

Generally, students take Part I in common with the other engineering students in the School and will enter Part II enrolled in either the Mechanical Engineering or the Mechatronics degree programmes. The general intention is that these students have received a core education in Mechanical Engineering by the end of semester 1 in Part III. Thus Part II and the first semester of Part III will be common to all Mechanical Engineering students, after which the students can make the final decision to proceed on the traditional Mechanical Engineering path or choose to specialise in Mechatronics for the last 18 months of their degree. There is, however, a mechatronics component to the Part II course for all mechanical/mechatronics students.

Significant specialisation thus occurs from the second semester of Part III, when Mechanical Engineering and Mechatronics students will take substantially different courses of studies. We believe that Mechanical Engineering students should also have some early exposure to Mechatronics concepts. Thus it was also proposed that a Mechatronics project be included in the second semester of the Part II Engineering Design course.

Substantial project-based experiences have to be included in the course, because these are necessary to fully appreciate issues concerning modelling, control, simulation, design and construction of mechatronic devices.

Implementation Considerations

There are many considerations regarding the detailed implementation of the degree, and a few of these are raised here.

***Microprocessors and hardware*.** There are a number of pitfalls in the teaching of microprocessor-based technologies that must be avoided. Experience obtained in courses at, for example, Purdue University [7] and MIT [8], suggested a number of relevant issues that should be addressed in developing microprocessor courses, namely:

- Maintaining currency in topics covered in the presence of continuous advances in microcomputing technology;
- Choosing appropriate hardware that balances opposing financial requirements;
- Choosing appropriate software for the time constraints in the course;
- Providing meaningful hands-on laboratory experience.

Broadly, of course, we intend to provide an education, rather than training in current hardware/software. This is required because rapid advances will continue to be made in the coming years, and our graduates must be able to adapt to thrive. Thus an obsession with maintaining currency can obscure some of the important pedagogical considerations. Our philosophy is to encourage the teaching of basic concepts involving microprocessor architecture, programming and interfacing on simpler platforms, realising that the students will work with different hardware in their future careers. Therefore the key is to find a platform that teaches these fundamental concepts well.

Maintaining currency in hardware can also place an unreasonable burden on the course. Given the diminishing funding from central New Zealand government we had to recognise these financial constraints and plan accordingly.

Software. The choice of appropriate software can be equally problematic. There will be a course in Part III, which would cover the basics of assembly language together with a high level language used extensively for real-time programming such as C or C++. We proposed using Matlab and associated tools (toolboxes, Simulink etc.) extensively for general technical computation.

Resource Implications of Projects. The design-and-build projects form a major component of the final year of the proposed course. If the course is to thrive, we stressed that the host department, the School and the academic staff must be committed to a hands-on approach to design, and instructors must be committed to providing students with the necessary guidance to ensure that projects are successful. Each student will do two major projects in Part IV: a microprocessor design and interfacing project in the first semester and an innovative Mechatronics system design in the second semester. It was proposed that the second semester project would run along lines similar to those of the course '*Designing Smart Machines*' at MIT [8], or the Mechatronics design projects at Polytechnic University in Brooklyn, [9]. The average budget for each project at Polytechnic University was then $US500, which represents a substantial financial commitment from university or industrial sources to make these projects a success.

Student and Industry Demand

Preliminary informal surveys of engineering students in Parts II through IV revealed enormous interest. Many students did not know what the word 'Mechatronics' meant but were genuinely excited by the high-tech, modern machine/microprocessor reality. With a minimum of advertising or pushing, we felt that it would not be difficult to tempt students to enrol for this degree.

A written survey of Part I students was conducted. Part I is common to all engineering students, and upon completing it, they enrol in specific degree courses. In this survey the students were asked two questions:

1. What degree do you want to enrol in next year?
2. Suppose a Mechatronic Engineering degree were running in 2000. Would you want to enrol in it? (1=Definitely NOT, 5=Neutral, 9=Definitely).

The results showed a very strong interest in this degree. Of the 302 responses, 44 (14.6%) and 42 (13.9%) answered 9 or 8 respectively to question 2. If this proportion of students were to enrol, it would have by far the largest enrolment in the School of Engineering at Auckland. A number of students followed this up by asking whether any Mechatronics options could be provided for them.

155 questionnaires were sent out to industry. The majority (if not all) of the companies on the list carry out Mechanical Engineering type work of some sort. The general reaction towards the introduction of a new degree that produces graduates with fundamental training in Mechanical Engineering and specialisation in Mechatronics, was extremely positive. Out of the 72 replies 57 (79.2%) thought that the degree is definitely needed for New Zealand's present and future industry and economy. Nobody thought it wouldn't be needed.

Conclusions

The arguments contained in the full proposal were sufficient to sell the idea of the degree and the department voted unanimously at a meeting to proceed with its development. The new degree was approved at the end of 2000 and then entered in the University Calendar for the next year. Part II students then had the option of choosing to enrol in the degree from 2001.

Initial indications are that the projections have been proved so far. There was a limit on the first intake of 35 students and such was the popularity of the degree that entry to the degree could be restricted to students who obtained an average of B or better in their first year. This entry requirement is much stronger than most of the other degree courses.

CASE 2: PROPOSAL FOR A EUROPEAN-WIDE DEGREE

The definition of what constitutes a mechatronic system can be quite wide. In fact in Tomizuka's 'Y2K' definition he has replaced 'mechanical systems' (from the IEEE/ASME Transactions definition) with 'physical systems' to emphasise the diversity of mechatronic systems.

This second example of an academic course in Mechatronics is application specific and the course name is derived from that – though it is not too difficult to recognise that the application is a mechatronic one. It is interesting because it highlights the breadth of possibilities in creating a mechatronic-type course, as long as it retains the basic concept of multi-disciplinary thinking by individual engineers. ASSET is a European Union Thematic Network for 'Applications of Smart Structures in Engineering and Technology.' Two of the authors of this paper are members and attend the meetings regularly. One of the objectives of the network was to propose and eventually develop an educational route for engineers with expertise in smart structures. Professor P.F. Gobin proposed two possible approaches at the ASSET meeting held in Berlin on December 5^{th} and 6^{th}, 2000. The first proposal was along lines similar to those described in Example 1, except of course the emphasis is towards smart materials and structures. The second proposal is more innovative as it embraces distance learning.

The Virtual European University on Smart Materials, Structures and Systems

The main element of this was the creation of a quasi virtual European University on 'smart materials, structures and systems'. To do this Professor Gobin proposed the easiest solution, that is, the use of the ASSET website (www.assetnet.org), already created as part of the network objectives, as the 'heart' of such a project.

Of course, any degree programme that is mechatronic in nature cannot be purely 'virtual' because of the requirements of laboratories and design-and-build. The internet could be used to set up web-based laboratories located at 'centres of excellence' around Europe but the design and build element, which is so crucial, cannot be replicated on the web. Professor Gobin therefore proposed a European Network of 'Centres of Excellence' (made up of some of the ASSET partners) which can offer students the scientific and technical support necessary to complement theoretical work carried out via the web.

This type of structure would seem to be most compatible with a postgraduate course with the student obtaining a master's degree (being awarded by the European university) on the basis of an exam, oral presentation and practical demonstration of a smart device. The practical emphasis will change depending on the centre of excellence the student chooses.

CONCLUSION

This paper provides an introduction and overview of both industrial and academic issues regarding Mechatronics. It has highlighted the importance of mechatronic engineers, that is, engineering designers who can think both within and across different disciplines to industry. What is meant by 'Mechatronics' was discussed and the academic issues regarding the generation of engineering graduates in Mechatronics considered. Many of these issues are addressed in the first case study, which concerns the development of a mechatronic engineering degree at Auckland University. The second case study is provided to highlight the diversity of courses that could be termed 'mechatronic'.

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