The Place of Mechatronics within the Faculty Structure – a Personal View

John Billingsley
Faculty of Engineering and Surveying,
University of Southern Queensland, QLD, Australia
billings@usq.edu.au

Abstract—**After quarter of a century, Mechatronics still has difficulty in being recognised as a discipline in its own right. Typically found under the wing of mechanical or electronic engineering, the syllabus is all too often overstuffed with specialist material. What is the essential role of the mechatronic engineer and what topics are essential to the syllabus?**

Keywords—**Mechatronics, syllabus, mechatronic engineer.**

1 INTRODUCTION

At a meeting that I chaired in St Albans in 1992, sponsored by the UK Institution of Mechanical Engineers, considerable effort was devoted to the defining the meaning of the term ‘mechatronics’. Words like ‘synergy’ were thrown about with abandon, but the consensus was in agreement that mechanical engineering and software engineering, electrical engineering and control theory were all involved somehow.

In my opinion a university course in mechatronics will all too often try to cover the whole of every aspect. Reviewers with a specialisation in mechanical engineering will insist that all aspects of materials, thermodynamics and finite element analysis of gear-tooth stresses be included. Electrical engineers will complain if the theory of the p-n junction in terms of Fermi levels happens to be omitted.

I would regard my own specialization as control theory. Sometimes this is ‘owned’ by a mechanical engineering department and sometimes by the electricals. Surely it must be regarded as a distinct component of mechatronics in its own right. But then I must question my own bias towards control.

An important task of any engineer is to select between the many possible paths to a solution. An electrical engineer will be happy to devise an ingenious drive circuit for a three-phase motor. A mechanical engineer will know the machining tolerance that is necessary for an interference fit. But it takes a mechatronic engineer to make a trade-off between adding some lines of software and reducing the precision needed for a mechanical assembly. An example is the ‘three-in-one’ colour printer, where the requirement for twenty micron printing precision is achieved by requiring the purchaser to print a test-sheet, scan it and allow the software to make automatic adjustments. That is surely mechatronics in action.

The mechatronic engineer must be adept at designing feedback circuitry around an operational amplifier, but has little need for an ability to design the chip itself, nor for the finer intricacies of biasing a discrete-component amplifier. On the other hand he must be aware of dissipation limits in a power drive circuit and the possible dangers of thermal runaway.

He must control the overview of a complete design, trading off the various technologies to decide which aspects to delegate to narrow specialists, just as a medical general practitioner assesses the whole patient and calls in the services of a consultant if needed, or an architect knows the merits of an assortment of grades of concrete, but would never be expected to mix it himself.

In an ideal world a mechatronics programme would contain just those factors that are essential. The sad reality is that the economics of course development will usually require the programme to share many underpinning courses with the discrete specialities, including the bag and baggage of many decades of tradition. Perhaps some resolute mechatronic course design can result in teaching material that the specialists will want to share.

A great concern when reviewing a mechatronics course should therefore be to identify material that can be left out, rather than cramming the head of the student with the intricacies of every conceivable topic.

2 WHAT ARE THE COMPONENTS OF A MECHATRONICS COURSE?

The glib quick answer is "mechanical engineering plus electronic engineering, that's what the name means, doesn't it?" But it is necessary to look much deeper than that. Aspects of these topics are certainly involved, but an overview of software techniques must certainly be included together with the control theory necessary to support them.

2.1 Mathematics

Sitting underneath all of these topics is the bugbear of most engineering students, Mathematics. Perhaps by taking the example of mathematics, I can gain some sympathy from the electronic or mechanical engineers who must by now be bristling with indignation. I looked up the syllabus of the Cambridge Mathematics Tripos [1], something I took over fifty years ago. The changes were surprisingly few!

Some of the topics in the first year, Part 1a, are familiar to most engineers,

Vectors and Matrices	Analysis I
Differential Equations	Probability
Groups	Vector Calculus
Numbers and Sets	Dynamics and Relativity.

But far from an engineer's interpretation of 'analysis', Analysis 1 is preoccupied with Limits and Convergence, Continuity and Differentiability, while Integration concerns the Riemann integral, leading up to the Lebesgue integral of 'non-integrable functions'. And that is just the first year! In the second we see

Linear Algebra	Groups Rings and Modules	Complex Methods
Analysis II	Metric and Topological Spaces	Complex Analysis
Geometry	Variational Principles	..and much more

Clearly the syllabus for a specialist mathematics course goes a long way beyond anything needed by a mechatronic engineer, or by any engineer for that matter. Perhaps you will agree that the specialist electrical and mechanical syllabi are equally overloaded.

So what mathematics does a Mechatronics student really need?

In some minds, Mechatronics and robotics are synonymous, although I consider robotics to be one small aspect of Mechatronics. Nevertheless the needs of robotics must be addressed and therefore the ability to juggle with vectors and matrices is essential. Robot singularity calls for an awareness of matrix rank, while vibrational modes and control theory both call for skill in eigenvalues and eigenvectors.

Mathematical operators such as grad, div and curl are mainly of use in analysing fluid flow and electromagnetic waves. Are these necessary for mechatronics? Certainly other operators, such as the property that a total derivative of position can include a partial derivative and the cross product with an angular velocity, will be essential for a full study of dynamics.

Control theory is another heavy consumer of mathematical theory. Differential equations are clearly a necessity, but some of the conventional teaching material might be a matter for debate. Many control courses consider only systems that are linear and often amount to “Everything you ever wanted to know about the Laplace transform.” It could be argued that the ability to simulate systems, including nonlinear ones, could be more important then the ability to derive an analytic solution.

The state-space approach opens the way to derive equations from a physical system, leading straight to algebraic analysis of linear systems and simulations of systems with all conceivable nonlinearities. Once again eigenvectors spring to the fore.

2.2 Electrical engineering and electronics

The Mechatronic engineer must be able to select from a wide variety of motors, DC, induction including single-phase with starter, hysteresis, drag-cup, universal, multiphase, stepper, linear, solenoidal, piezo and others. Torque-speed characteristics, efficiency and appropriate drive electronics are all of great interest, especially the H-bridge for driving a DC motor. But three-phase transmission lines are unlikely to have much significance for a mechatronic engineer, nor many other power engineering topics.

Semiconductor theory is all too often taught with trimmings of conduction and valence bands, Fermi levels and face-centred cubic lattices. The interest of the mechatronic engineer is surely limited to the performance of devices, be they bipolar or field effect power transistors or an integrated circuit. Skill in the deployment of operational amplifiers is essential, but the biasing of a discrete component amplifier is much more questionable.

Some knowledge of electronic logic is needed, but maybe the construction of a full adder from electronic gates is going beyond the bounds of necessity. Petri nets are likely to be more useful than Karnaugh maps.

A familiarity with Maxwell’s equation through a study of fields and waves might be ‘good for the soul’, but a knowledge of communications is more useful in the form of proficiency in transmitting commands and data over SCADA, CANBUS and legacy protocols.

Many other topics require some awareness, such as electromagnetic compatibility.

2.3 Mechanical engineering

Most of dynamics will be needed. Many of the secrets of gearboxes will be valuable, although tooth-profiles will be less so. But most of a materials course is only of interest at the level of application properties. Pearlite, stellite and the bonding agents of fibre composites can all be left to the specialists.

Unless the mechatronic engineer is concerned with aquatic vehicles, most of the details of fluid dynamics will be irrelevant. The analysis of hydraulic drives will require little advanced theory and pneumatic systems only a little more.

It is however possible that some aspects of thermodynamics will be useful. Not steam tables or the Carnot cycle, however, but topics of conduction and convection cooling.

Mechanical and electrical engineers may sometimes seem poorly prepared when sharing units of power and energy. Both are often surprised by the power of a watt to lift a load, although the relationship between a Joule and a Newton-metre is glaringly obvious. The matching of a load to a source involves the same algebra whether mechanical or electrical.

2.4 Control theory

It is remarkably easy to list topics of a control course that are not relevant for the mechatronic engineer. Although stability and analysis of dynamic response are essential topics, the mechatronic engineer will have little use for quadratic cost functions, the two-endpoint problem, the Jordan Canonical Form or even H-infinity control.

Some trends in control theory seem to be designed to have a psychological impact rather than an intrinsic usefulness, except perhaps for the marketing of add-ons for packages like

Matlab. ‘Fuzzy’ techniques have departed from the original concept of control with incomplete data and now represent a cult variety of piecewise-linear feedback elements.

Students must be aware that such techniques are a subset of the more powerful set of non-linear strategies, rather than something magic. An analogy is the current hype for cloud computing. Users must be aware that rather than sitting on a cloud, their data will be stored on a disk in some unspecified location.

Most mechatronic control will be digital, meaning that an ability to design and analyse discrete-time systems must be fundamental. But an alternative approach to teaching the techniques is suggested later in the paper.

2.5 Software

In days gone by, the mechatronic enthusiast would be adept at harnessing an eight-bit microcontroller such as the HC11, Z80 or Stamp to perform such tasks as the Micromouse Contest, where robot ‘mice’ had to explore a maze and find their way to the centre.

Perhaps there is still room for including experiments with an Arduino or its successors. Programming at a low level can alert to the engineer to the pitfalls of multi-threading, rather than imagining that processes are truly parallel.

(Long ago, before the invention of the ‘stack’ I wasted a week hunting a bug that resulted from sharing a subroutine with two separate interrupt routines.)

There are many powerful simulation and development tools such as LabView and D-Space, but there is a great danger in thinking that drag-and-drop is the answer to all problems. Students must be aware of what is ‘under the bonnet’.

Even with the impressive power of recent processors tasks can be time-critical. Mechatronic engineers must have the know-how to direct their specialist software writers to get ‘down and dirty’ to avoid the inefficiency of coding at a high level.

2.6 Further topics

We have all suffered from the well-designed product that is let down by a user manual that is written in Chinglish. Surely the influence of the mechatronic engineer must extend to the user documentation. If a feature cannot be described clearly, it might as well not exist except as an ‘Easter Egg’ for the user to discover by accident.

Ergonomics, the user-machine interface, is another aspect to consider. This can range from the complexities of a Graphic User Interface to a consideration of the nature and number of knobs, or the illegible black-on-black embossed legends with which the controls are labelled.

Compare the simplicity of the controls of an iPod with the numerous buttons on the average TV remote.

3 THE Z-TRANSFORM, AN ALTERNATIVE APPROACH

Computer control is an inescapable part of mechatronics. That implies that the z-transform will be of great use, not only to analyse the discrete-time performance of a physical system under digital control, but also to synthesise and analyse filters that are implemented in the form of software.

The z-transform is usually regarded as the last step in a long chain of mental gymnastics. First the student has to come to grips with differentiation, in which a ratio must be taken of small increments that both tend to zero.

Many years ago the solution of differential equations was assisted by use of the D-operator. This was supplanted by the Laplace transform, so that initial conditions could be incorporated into the solution by algebra. But the reality is that only the notation is really used, since mathematical inversion of the transform involves an infinite integral over an oblique path. As generally taught, inverting a transform involves 'solution-spotting' with the aid of the uniqueness theorem.

Such solutions usually involve exponentials of time, with a need to understand that the exponential of an imaginary time is a sine or cosine function.

A further mental obstacle is the fact that the unit Laplace transform represents an impulse, a signal of infinite amplitude with infinitesimal width. The analysis of computer-controlled systems with continuous dynamics is therefore beset with impulse modulators, while real systems are instead constructed of samplers and digital-to-analogue convertors.

The z-transform is usually taught as an extension of the Laplace transform. Representing a D-to-A convertor presents further difficulties, requiring the continuous system to incorporate an extra integrator, while the z-transform equivalent must be augmented by an extra multiplying factor $(1 - z^{-1})$.

Suppose instead that we teach the z-transform from first principles. In the same way that the Laplace ‘s’ implies differentiation, z can be interpreted as ‘next’.

Solutions will involve powers of an eigenvalue, k, rather than exponentials. Even when this is complex, representing an oscillating response, the relationship of the variable to the real part of k^n is intuitive. The requirement that k should lie inside the unit circle is easily understood.

Instead of relying on transfer functions in 's', a state-transition matrix can be derived empirically. If we have a second order integrator with an input u that is constant within the time step, the solution can be integrated straightforwardly to give

$$z\begin{bmatrix} x \\ v \end{bmatrix} = \begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix}\begin{bmatrix} x \\ v \end{bmatrix} + \begin{bmatrix} T^2/2 \\ T \end{bmatrix} u$$

in which the z denotes ‘next’. Now the equation can easily be manipulated algebraically to give a z transform.

The same principle can be applied to software algorithms, such as those for implementing filters.

If implemented at regular intervals T the code:

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y = y + a*(x-y)*T;
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will implement a low-pass filter with input x and output y. If we insert a z before the first y, indicating that it is a new value, we can find the z-transform by simple algebra

$$y = \frac{1}{z - 1 + aT} x$$

By the same token, an estimate of the velocity can be made as a multiple of (x – y).

4 CONCLUSION

It seems to me that organisers of mechatronics courses should be more assertive of their status within the faculty hierarchy. Rather than being ‘owned’ by one of the traditional disciplines, they should follow the lead of the increasing numbers of departments of mechatronic engineering.

Indeed faculties of mechatronic engineering can be found in Poland and Czechoslovakia [2,3]. Is it possible that such a department or faculty could claim ownership of electronic and mechanical engineering as mere specialisations?

But if that is an unattainable goal in our own countries, then at the very least the material should be trimmed to the needs of the mechatronic engineer, rather than serving every requirement of the specialist [4,5].

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