1-1-2005

# Maintaining a balance at undergraduate degree level in the teaching of automation and classical control systems

Eugene Coyle
*Dublin Institute of Technology*

Aidan O'Dwyer
*Dublin Institute of Technology*, aidan.odwyer@dit.ie

# Maintaining a Balance at Undergraduate Degree Level in the Teaching of Automation and Classical Control Systems

**Eugene Coyle** BE MSc PhD CEng FIEI MIEE AMInstMC
**Aidan O'Dwyer** BE MEng PhD CEng MIEE CEng MIEI
Department of Control Engineering,
Dublin Institute of Technology, Ireland.

Advances in the past decade in the development and application of Programmable Logic Controllers (PLCs) and Automation Systems in both high technology industrial plants and in the more mainstream manufacturing sectors, has heightened the importance of ensuring that undergraduate degree programme syllabi are designed to adequately cater for the teaching and training of students in automation. Prior to this growth in automation, delivered syllabi in Control Systems on most Electrical Engineering programmes had a theoretical rigour, reflecting the mathematical nature of the topic. A major challenge currently facing departmental lecturing staff and programme coordinators is that of the design of balanced programmes in Control and Automation Systems, to adequately reflect the importance of both streams. Owing to the applied nature of automation systems, a move towards a more Problem Based Learning teaching methodology in delivery of modules would seem the preferable way forward. At the same time, design of a balanced programme will require inclusion of sufficiently in-depth modules in classical control and process control, in order that graduates are provided with a good theoretical grounding in the subject, allied to practical hands-on experience in laboratory and project work. In summary, academic staff have the responsibility of providing the educational basis necessary to equip students with the skills required to cater for the needs of industry, while also providing a research arm for students who may wish to advance by way of postgraduate study to higher degrees.

Dublin Institute of Technology is Ireland's largest third level Institute, with different Faculties located on sites throughout the city of Dublin. The Faculty of Engineering caters for up to 3000 students with a full range of programmes including apprenticeship, certificates, diplomas, three-year ordinary degrees, four-year honours degrees (full-time), equivalent standard honours degrees (part-time), taught masters degrees, and funded research MPhil and PhD degrees. The Faculty contains five Schools: Control Systems and Electrical Engineering, Mechanical and Transport Engineering, Manufacturing Engineering, Electronic and Communications Engineering, and Civil and Building Services Engineering. An important and prided feature of DIT policy is that of it's *ladder system* by which students may progress from apprenticeship and certificate programmes right through to MPhil and PhD degrees.

Within the School of Control Systems and Electrical Engineering, there are three departments, Control Engineering, Electrical Engineering and Electrical Services Engineering. The School has developed over several decades; its earlier focus was in preparing students for the examinations of the UK-based institutions, in particular the

City and Guilds of London Institute and the Engineering Council. Currently, the school offers three undergraduate degrees in Electrical Engineering:

1. An ab-initio full-time three-year ordinary degree (Bachelor of Engineering Technology) with two main streams: *Control and Automation Systems* and *Electrical Energy Systems*. This degree is an upgrade and reformulation of a previous three-year diploma; it provides the education component for IEng registration and is thus comparable with a UK HNC/HND award, or equivalent.
2. An ab-initio full-time four-year honours degree (Batchelor of Engineering) with a modest level of specialisation in the following areas: *Communications Engineering*, *Computer Engineering*, *Control Engineering* and *Power Systems Engineering*. This degree is accredited by the Institute of Engineers of Ireland; it provides the education component for CEng registration and is thus comparable with a UK Batchelor of Engineering award at honours level, or equivalent.
3. A part-time honours degree equivalent to the ab-initio four year honours degree. This degree (Batchelor of Engineering) also provides the education component for CEng registration.

A sharp distinction has been drawn between the three-year ordinary degree and the honours degree (either full time or part time) at DIT. The entry requirements are different: for the ab-initio four-year honours degree, students are required to achieve a higher grade in the Honours Mathematics stream of the Irish second level terminal school examination (Leaving Certificate), or equivalent; for the three-year ordinary degree, students are required to achieve a higher grade in the Pass Mathematics stream of the Leaving Certificate, or equivalent. The ordinary and honours degrees do not share any courses in common; courses have a more practical orientation on the ordinary degree, and have a more analytical orientation on the honours degree. This is entirely consistent with the different educational focus of both degrees, as formulated by the professional engineering institutions.

It is proposed to present an overview of the design and delivery of syllabi content in control and automation systems on the three undergraduate degree programmes mentioned. Syllabi content are generally aligned with the strategic objective of the DIT, which is to maintain all its programmes closely allied with, and responsive to, industry. The content of the degrees will be compared to demonstrate the sharp distinction mentioned in the previous paragraph; in addition, details of the *ladder system*, which allows students the opportunity to move, on completion of the ordinary degree programme, to either of the honours degrees will be provided.

## Batchelor of Engineering Technology Programme Curriculum

As mentioned, this is an ab-initio full-time three-year ordinary degree with two main streams: *Control and Automation Systems* and *Electrical Energy Systems*. The programme covers a broad range of topics in electrical engineering, with students selecting one of the two major stream specialisations in Year 2 of the programme and carry on with this stream into Year 3 of the programme. In the formulation of the programme, a decision was made to place a greater emphasis on continuous assessment than in the previous programme and this is reflected in a significant increase in allocation of marks to continuous assessment. For those subjects that have an end-of-year examination component, the combined elements comprising continuous assessment have an equal weighting with the end-of-year sessional examinations.

In Year 1, all students take Mathematics, Engineering Science, Engineering Computing, Electrical and Electronic Systems, Electrical Engineering Practice, Professional Development and one option subject. The option may be either one from a group of subjects on offer by the School of Languages, or Mechanical Workshop.

In Year 2 students must choose a major core path in either *Control and Automation Systems (module 1)* or *Electrical Energy Systems (module 1)*. In addition, all students study additional modules in Mathematics, Engineering Computing, Electrical and Electronic Systems, Industrial Electronics, Professional Development and one option (chosen from either a list of options offered by the School of Languages, or one of either Mechanical Building Services or Industrial Computing and Network Management.

In Year 3 students continue with the selected major stream chosen in Year 2, i.e. *Control and Automation Systems (module 2)* or *Electrical Energy Systems (module 2*). All students study additional modules in Project Management, Industrial Electronics, and *two* other option subjects from the following list: Electrical Services, Systems Engineering, Control and Automation Systems (minor), Electrical Energy Systems (minor), Mathematics, Circuits and Systems, Language/Cultural Studies. Students may not select a minor subject from the same stream as their major subject. In addition, students undertake a final-year project, which runs for ten weeks on a full-time basis from the end of their final examinations (the project normally runs from mid-March to the end of May).

**Batchelor of Engineering (full time) Programme Curriculum**

This is an ab-initio four-year honours degree programme. The programme covers a broad range of topics in electrical engineering. Assessment is by means of written examinations and continuous assessment, with the latter normally comprising one third of the weighting of the corresponding written examination, for each subject.

In Years 1 and 2, the scientific and technical base of the programme is established. In Year 1, all students take courses in Mathematics, Physics, Applied Mechanics and Properties of Materials, Electrical Systems, Electronic Systems, Computing, Design, Communication Studies and a Language. These subjects are taught at a higher level than corresponding subjects in Year 1 of the ordinary degree programme, reflecting the course ethos and the students' background. The distinction between the ordinary degree and honours degree is deepened in Year 2 of the honours degree, in which all students take courses in Mathematics, Electronics and Solid State Physics, Electrical Systems, Electrical Machines and Power Systems, Computing, Design, the Engineer in Society and a Language.

The first semester of Year 3 completes the technical base of the programme. Students take courses in Statistics, Electronics, Computer Systems, Field Theory, Business Studies and a Language. In addition, all students take introductory courses in Instrumentation and Measurement, Control and Automation, Communication Systems and Electrical Power Systems. In the second semester of Year 3, all students follow a core curriculum in Mathematics, Electronics, Computer Systems, Circuits, Signals and Systems and Business Studies; in addition, students choose a major subject from *Communications Engineering*, *Computer Engineering*, *Control Engineering* or *Power Systems Engineering*. These subjects are continued into Year 4, with students additionally choosing an elective subject; in the current academic year, the elective subjects are *Wind Energy*, *Time Delay Systems* and *Microware and RF Engineering*.

The ordinary and honours degree programmes are sharply differentiated. It has been the practice that students who receive an average mark of 65% or greater on the ordinary degree programme, or equivalent programme, are considered to have sufficient background to enter Year 3 of the honours degree programme; in addition, ordinary degree students must have studied Mathematics in Year 3 of their programme as one of their option subjects. This subject requirement, and the overall achievement level specified, has been found in practice to equip students sufficiently for the higher degree programme, bearing in mind the inevitable mismatches between the two programmes. Students who have successfully graduated from the ordinary degree programme, or equivalent programme, who do not fulfil the two requirements mentioned, are permitted to enter Year 2 of the honours degree programme.

**Batchelor of Engineering (part time) Programme Curriculum**

This is a four-year, post ordinary degree (or equivalent), part-time honours degree programme. The course content of the part-time programme is somewhat similar to that of Years 3 and 4 of the full-time honours programme; there major difference is that two major subjects are chosen in the part-time programme, with a consequent lesser degree of specialisation than on the full-time programme. In addition, the part-time programme places somewhat less emphasis on laboratory work, as almost all students have significant practical experience developed in the course of their employment. Students can enter Year 1 of the part-time programme with an average mark of 60% or greater on the ordinary degree programme (or equivalent).

# CONTROL AND AUTOMATION SYLLABI

**Batchelor of Engineering Technology**

The aim of the *Control and Automation Systems (module 1)* course is to enable the student gain knowledge and practice of implementing the automatic control of various industrial and manufacturing processes. Six teaching hours per week, over 28 weeks, is devoted to the subject, *half* of which is spent in the laboratory. An outline syllabus is as follows:

| | |
|---|---|
| **Outline Syllabus**<br><br>**Year 2**<br><br>**Control and Automation Systems (module 1)** | ▪ Product and position detection sensors for limit and proximity detection. Analogue level sensing techniques. Actuators.<br>▪ Hardware and software structure of an industrial computer. Operation cycle of an industrial control computer.<br>▪ Wiring of a control system and safety issues.<br>▪ Logical control of an industrial process.<br>▪ Introduction to software engineering techniques.<br>▪ Discrete control elements in automation. Data handling in an industrial computer. Computer communication techniques.<br>▪ Control of a sequential process; series and parallel sequences, loop sequences and automation of a process with a sequence. |

| | |
|---|---|
| | ▪ IEC 1131-3 sequential control programming.<br>▪ Open loop and closed loop control. ON/OFF control, proportional control of analogue processes.<br>▪ Introduction to a high level programming language. |

The laboratory schedule includes an introduction to programming software to control an air conditioning system and project work involving the control of conveyer and sorting machines. Assessment is carried out in the laboratory by examination of the student's laboratory work and developed software, and by examination of the presented solution. The student is required to take an oral and practical examination and to present a folder at the end of the course with all of the laboratory exercises fully documented.

*Control and Automation Systems (module 2)*, introduced in Year 3 of the programme, builds upon the second year module, with emphasis on the control and automation techniques utilised in a modern process or manufacturing facility. Six teaching hours per week, over 19 weeks, is devoted to the subject, again *half* of which is spent in the laboratory. An outline syllabus is as follows:

| | |
|---|---|
| **Outline Syllabus**<br><br>**Year 3**<br><br>**Control and Automation Systems (module 2)** | ▪ Measurement of level, pressure, temperature and flow. Calibration techniques.<br>▪ Practical transmission-media including: optical fibre, co-axial, twisted pair, LANs and WANs, cable routing, OSI-ISO/TCP-IP, packet switching, network topologies.<br>▪ Industrial Computer networks and Fieldbus systems.<br>▪ Distributed control of manufacturing processes.<br>▪ Implementation of PID control of processes using an industrial computer. Tuning and optimisation of PID controlled processes.<br>▪ Variable speed control of motors. Digital position control systems. Robotics.<br>▪ Computer sampling rates, and the stability of processes under control by computers.<br>▪ Data information systems for integration of the manufacturing process. Flexible manufacturing systems. Use of automatic material handling and robotics.<br>▪ High-speed control, interrupts and high speed processing.<br>▪ Data handling in an industrial/automation computer.<br>▪ Management control of processes and management reporting. Use of high level computer language to gather, present and report production and management data. |

An active hands-on laboratory programme again forms an important part of the Year 3 programme and includes the automation of assembly and sorting processes, PID control of an automation application and laboratory exercises in remote I/O and Fieldbus I/O. Students are again required to submit regular reports, complete small projects and present for an end-of-semester oral and practical examination.

In addition to the main core option in Control and Automation Systems in Year 3, students may choose the following option subjects:

- *Control and Automation Systems (Minor)*: Designed for students following the *Electrical Energy Systems* major stream only, the syllabus content is a judicious mix of the Control and Automation Systems Year 2 and Year 3 core option, with emphasis on the Year 2 material.

- *Systems Engineering*: The syllabus is that of a more traditional control engineering option, and the aim of the subject is to provide the student with a practical understanding of the principles the subject, at a level equivalent to graduates of HNC/HND courses. Five teaching hours per week, over 19 weeks, is devoted to the subject; *three* of the five teaching hours are spent in the laboratory. An outline syllabus is as follows:

| | |
|---|---|
| **Outline Syllabus**<br><br>**(Control) Systems Engineering** | ▪ Examples of open and closed loop systems. Mathematical models. Introduction to steady state error and stability.<br>▪ System Models: Mechanical, Electrical, Fluid, Thermal systems. Block diagram modelling.<br>▪ System responses. Uses of the Laplace transform.<br>▪ Stability – poles. Routh-Hurwitz criterion. Root locus analysis.<br>▪ Frequency response – Bode plots, Nyquist diagrams. Gain margin/phase margin.<br>▪ Controllers – On-off, P, I, PI, PD, PID. Controller tuning. Velocity feedback. Electronic, pneumatic and discrete time implementations.<br>▪ Sampled data systems. Zero-order hold. Using z-transforms. Sample period. Translation of analogue control laws. Stability.<br>▪ Practical control loop implementation: transmitters. Control valves - sizing.<br>▪ Introduction to advanced control techniques: feedforward control, cascade control, time delay compensation. |

Laboratory work closely supports the syllabus content, with significant laboratory time devoted to the control of pilot scale industrial plants.

**Batchelor of Engineering (full time) Programme Curriculum**

As mentioned, all students in Semester 1 of Year 3 take modules in the two subjects *Instrumentation and Measurement* and *Control and Automation*. In Semester 2 of Year 3, students can choose a major subject in *Control Engineering*, which is continued into Year 4. In Year 4, students can additionally choose an elective control engineering subject, called *Time Delay Systems*. Details of all of these subjects are provided below.

The aim of the *Instrumentation and Measurement* course is to allow students to gain an understanding of the scientific principles of various sensors and the design and operation of a measurement system. Three teaching hours per week is devoted to the subject over 16 weeks; one of the three teaching hours (on average) is spent in the laboratory. An outline syllabus is as follows:

| | |
|---|---|
| **Outline Syllabus**<br><br>**Instrumentation and Measurement** | ▪ The measurement system: principles. Errors. Static and Dynamic characteristics. Standards.<br>▪ Electronic measurement fundamentals - includes instrumentation amplifiers, electrical noise, interference and grounding issues, and the use of ADC and DAC elements.<br>▪ Measurement of non-electrical quantities including temperature, pressure, flow and level.<br>▪ Measurement of electrical quantities including voltage, current, resistance, capacitance and inductance. |

Laboratory work closely supports the syllabus content, with approximately 40% of the laboratory time devoted to the design, construction and testing of a temperature measurement system.

The aim of the *Control and Automation* course is to provide the student with the basic knowledge in this topic appropriate to an electrical engineer. Three teaching hours per week is devoted to the subject over 16 weeks; one of the three teaching hours (on average) is spent in the laboratory. An outline syllabus is as follows:

| | |
|---|---|
| **Outline Syllabus**<br><br>**Control and Automation** | ▪ Overview of the design of industrial processes. Continuous and batch operation.<br>▪ Automation – batch and sequential control in industrial processes.<br>▪ Modelling – the modeling of physical systems in continuous and discrete time.<br>▪ Identification – step response and frequency response. Reduced order modeling.<br>▪ Control of continuous processes – on/off, P, PI, PID. Controller tuning. Controller implementation.<br>▪ Performance criteria – time domain, frequency domain.<br>▪ Stability in the time domain, frequency domain and sampled data domain – Routh, Nyquist. Introduction to root locus. |

Laboratory work closely supports the syllabus content, with approximately half of the laboratory time devoted to automation application exercises.

The aim of the *Control Engineering (Major)* course is to provide the student with an in-depth knowledge of both the theory and practice of control and automation engineering. Five teaching hours per week is devoted to the subject, over 28 weeks; two of the five teaching hours (on average) are spent in the laboratory. The syllabus content is divided between *Control Systems* and *Automation*; in total, the Control Systems portion of the subject is taught for 56 hours in a lecture environment, supported by 18 hours laboratory work; the Automation portion of the subject is taught for 28 hours in a lecture environment, and for 38 hours in the laboratory. This division reflects the more applied nature of the Automation syllabus, together with more general pressure to reduce classroom and laboratory contact hours and the increasing desire to facilitate student self-learning.

To support the Control Systems part of the syllabus, considerable effort has been put into the use of computer aided design and analysis tools (specifically MATLAB/SIMULINK[1]); these tools facilitate student self-learning and enhance theoretical understanding and practical ability. In addition, virtual case studies in an interactive web environment have also been used; such interactive tools are a great stimulus for developing the students' engineering intuition. There has been a significant amount of work in recent years in the development of these tools (e.g. Garcia and Heck[2], Tilbury and Messner[3], Yang and Lee[4]). Some recent textbooks also have an associated website, with interactive features; the textbook by Marlin[5] is used on the major course and on the *Time Delay Systems* option course. The development of virtual laboratories has also been the focus of attention; virtual laboratories from a website associated with a recent textbook (Goodwin *et al.*[6]) are being used on the course.

An outline syllabus of the Control Engineering (Major) course is as follows:

| | |
|---|---|
| **Outline Syllabus**<br><br>**Control Systems Section**<br><br>**Control Engineering (Major)** | ▪ Review of PID controller tuning and implementation. Process and instrument elements of the feedback loop.<br>▪ PI/PID, phase lead and phase lag controller design techniques in the frequency and time domains.<br>▪ Robust control – sensitivity functions. Design of robust PID controllers.<br>▪ Non-linear systems – Linearisation. Characterisers. Control valves and their sizing. Phase plane analysis. Lyapunov stability. Describing functions. Dither signals and equivalent non-linearity.<br>▪ Adaptive control – Gain scheduling. Rule based methods. System identification – correlation testing, least squares techniques. Introduction to the use of expert systems, neural networks and fuzzy logic.<br>▪ Autotuning: Estimation of ultimate gain and period. Noise, gain and phase margin estimation. Determination of process model parameters. |

| | |
|---|---|
| **Outline Syllabus**<br><br>**Automation Section**<br><br>**Control Engineering (Major)** | ▪ Automation systems – alarm handling. Implementation of analogue control function blocks IEC 1131-1/2 (supported by 4 laboratory sessions).<br>▪ Sequence control language (supported by 3 laboratory sessions).<br>▪ Industrial computer networks and distributed systems. Distributed Fieldbus systems (supported by 2 laboratory sessions).<br>▪ Operator interfaces. Virtual Instruments – GPIB (supported by 1 laboratory session).<br>▪ Specification and validation of automation control systems.<br>▪ Production and manufacturing systems. Maintenance systems, Engineering and Production Control Systems, Management Information Systems. |

Finally, in Year 4, students can additionally choose an elective control engineering subject, called *Time Delay Systems*. This is a course on process control, which complements the largely classical control orientation of the Control Systems portion of the Control Engineering (Major) course. Four teaching hours per week is devoted to the subject over 14 weeks, half of which spent in the laboratory. An outline syllabus is as follows:

| | |
|---|---|
| **Outline Syllabus**<br><br>**Time Delay systems (Elective)** | ▪ Review of PID control. Mathematical modeling of systems. Time delays and their modeling.<br>▪ Empirical model identification – experimental issues. Continuous and discrete time controller tuning – process reaction curve methods.<br>▪ Identification in the frequency domain. Use of pulse tests to get frequency response data.<br>▪ Feedforward and ratio control. Cascade control. Selective and split-range control. MIMO systems – process interactions, pairing of controlled and manipulated variables, decoupling. Case studies.<br>▪ Time delay compensators in continuous and discrete time - Smith predictor, predictive PI controller, Internal Model controller, direct synthesis controller. Case studies. |

The part-time Batchelor of Engineering honours degree programme curriculum has two modules of *Control and Automation* in Years 3 and 4, respectively, as options. Altogether, 120 lecture hours and 60 laboratory hours are scheduled for the subject over the two years. The programme combines aspects of the *Instrumentation and Measurement*, *Control and Automation*, *Control Engineering (Major)* and *Time Delay Systems (Elective)* subjects in the corresponding full-time honours degree programme.

**Comparison between the ordinary and honours degree**

Table 1 below shows the class contact hours (both in lectures and laboratories) for both degree courses, for Control Engineering subjects. It is clear that more contact hours exist for the ordinary degree, particularly for laboratories. This is compatible with the more practical orientation of this degree. In addition, student self-study with the aid of web-based materials is a greater feature of the honours degree.

Table 1: Comparison of contact hours – ordinary degree and honours degree

| **Ordinary degree** | Lecture | Laboratory | Total |
|---|---|---|---|
| Control and Automation Systems - Year 2 | 84 | 84 | 168 |
| Control and Automation Systems - Year 3 | 57 | 57 | 114 |
| Total for Core Subjects | 141 | 141 | 282 |
| Systems Engineering Option | 38 | 57 | 95 |

| **Honours degree** | Lecture | Laboratory | Total |
|---|---|---|---|
| Instrumentation and Measurement | 32 | 16 | 48 |
| Control and Automation | 32 | 16 | 48 |
| Control Engineering Major - Automation | 28 | 38 | 66 |
| Control Engineering Major – Control | 56 | 18 | 74 |
| Total for Core Subjects | 148 | 88 | 236 |
| Time Delay Systems | 28 | 28 | 56 |

A close examination of the syllabi for the Control subjects in the two degrees will show some points of similarity in topics covered, particularly

- If the earlier part of the honours degree programme is examined
- If the automation syllabi in the two programmes are examined.

On the honours degree, a significant practical orientation exists, particularly in automation; however, it is clear that the material covered in the honours degree, both in the lecture and laboratory programme, is significantly different from that covered in the ordinary degree, in both quantity and breadth of coverage.

**Way Forward**

These are challenging times in Engineering Education, not least owing to the effort required to ensure a healthy student number intake to degree programmes is maintained. Challenges in addressing and tackling student retention issues are top of the agenda of most university programme committee teams in many countries throughout Europe. The good news is that with hard work and creative teamwork, it is possible to have some success in stemming the ebbing tide, and students indeed find that embarking on a career in Engineering can be *challenging, fun and rewarding.*

Our recent experiences at DIT have shown that offering creative laboratory tasks to first year students, such as the design of simple automated robots, generates a great deal of interest. Engaging students in this way is half the battle. With the additional help now available in the utilisation of software tools such as WebCT, creative design of lectures can brighten up and further contribute to the students' positive engagement. Designers of undergraduate engineering programmes need to put in the requisite energy and initiative to draw out the students' innate potential. It is important to maintain a clear distinction between ordinary and honours degree programmes, to allow students of different abilities to fulfil their potential.

In addition, the twin pressures of the need for students to learn a wider variety of concepts, ideally in a self-learning mode, and the reduction in class contact time has led to the use of increased levels of information technology in control engineering education. At DIT, work thus far has concentrated on the use of the MATLAB/SIMULINK computer aided design package to enhance student learning. Some work has also been carried out on the development of a graphic user interface to MATLAB/SIMULINK, to allow a more diagrammatic interface to the student (O'Dwyer[7]). It is anticipated that information technology, in all its manifestations, will have an accelerating impact on control engineering education.

**References**


1. www.mathworks.com
2. Garcia, R.C. and Heck, B.S., *IEEE Control Systems Magazine*, June, 77-82, 1999 (www.ece.gatech.edu/users/192/education/LSLNR)
3. Tilbury, D.M. and Messner, W.C., *IEEE Transactions on Education*, 42(4) 237-246, 1999 (http://www.engin.umich.edu/group/ctm).
4. Yang, D.R. and Lee, J.H., *Proceedings of the American Control Conference*, 683-687, 2003 (www.cheric.org/education/control)
5. Marlin, T.E., *Process Control: designing processes and control systems for dynamic performance*, Mc-Graw-Hill, 2nd edition, 2000. (http://www.pc-education.mcmaster.ca/course.htm).
6. Goodwin, G.C., Graebe, S.F. and Salgado, M.E., *Control system design*, Prentice-Hall, 2001 (http://csd.newcastle.edu.au/control).
7. O'Dwyer, A., *Using Information Technology to Enhance Control Engineering Education: Some Experiences*, presented at EdTech: The 5th Annual Irish Educational Technology Users' Conference, 2004.