Mechatronics at the University of Guelph

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Abstract

Today's engineering systems require multi-disciplinary design teams. In addition, the computer tends to now be an integral component of these complex systems. Our Engineering Systems & Computing (ES&C) program's objective is to provide the necessary background for the analysis and design of such systems. We have recently introduced options for our ES&C seniors, where one of the options is Mechatronics. In the Winter 2000 semester, our introduction to mechatronics course was successfully offered for the first time to our third year students. This course serves as the introductory course in our Mechatronics option which also includes courses in robotics, manufacturing and advanced mechatronics.

Sommaire

Les systèmes d'ingénierie d'aujourd'hui exigent des équipes multidisciplinaires pour la conception, l'entretien et le service. En outre, l'ordinateur est un composant intégral de ces systèmes complexes. Notre programme (ES&C) de systèmes et de calcul d'ingénierie étudie des systèmes où l'ordinateur est un composant intégral. Nous avons récemment présenté des cours à option à nos étudiants seniors dans notre programme d'CES&C où l'une d'elle est la mechatronics. Nous avons offert pour la première fois notre introduction au cours de mechatronics aux étudiants de troisième année. Le cours a été développé afin d'équilibrer la théorie et la pratique en laboratoire, les étudiants devant concevoir et construire un robot jouant au football. Cette formation a été donnée avec succès et tous les groupes ont développé un robot fonctionnel.

1.0 Introduction

Today's engineering graduates require a diverse set of skills, multi-disciplinary in nature, in order to solve the complex problems that employers and society demand. These multi-disciplinary skills typically cross over the traditional engineering disciplines such as electrical, mechanical and chemical. In addition, computers have become ubiquitous in today's society and have also become a standard engineering discipline at many Canadian engineering schools. The School of Engineering at the University of Guelph is unique with respect to the programs offered (Biological, Environmental, Engineering Systems & Computing, Water Resources) not neatly fitting into what some would consider the classical engineering disciplines. Actually, each program bridges more than one of the traditional areas. The ES&C (Engineering Systems & Computing) program is a relatively new program that was introduced in the early 1990s. It covers material that is typically covered in electrical, systems, computer and some mechanical engineering programs. One way of describing the ES&C program is "a study of systems where the computer is an integral component". It would be useful to our students if they achieved some specialization before completing their undergraduate engineering studies and therefore three options into the ES&C program were introduced: Biomedical systems, Embedded systems and Mechatronic systems. The students specialize in their third and fourth year by choosing one of these options. In practice, this requires the students taking four courses associated with the particular chosen option. The other engineering programs at Guelph are also introducing specialization options. The nurturing of cross-program dialogue is encouraged by some options actually being shared by programs. For example, the ES&C Biomedical option coincides with the Biomedical option in the Biological engineering program.

2.0 Engineering Systems & Computing Program

The Systems engineer requires to know how to identify and define a problem in addition to being a problem solver. Sometimes it is more difficult to define the problem, but this is a crucial step before a solution can be attempted. Even though students are always eager to engage in solving a problem, the design mentors continually stress the importance of initially having a well defined problem in order to explore design solutions. A well-defined problem statement also serves as a measuring stick to evaluate the final design against. The Systems engineer is concerned with the entire system and not just the components that comprise the system. An analogous profession would be an architect who oversees a large building project. Like an architect, ES&C graduates need to be well versed in an array of disciplines so that they can communicate with specialists in other engineering disciplines.

Our ES&C graduates obtain a diverse background in computer systems for the purpose of application into an assorted number of systems including industrial, biomedical, business enterprises and mechatronic to name a few. The ES&C educational program is an accredited professional engineering program. Fundamental courses in the areas of physics, math, chemistry, modeling, simulation, analysis, control and optimization form the core in the first couple of years of study. Given the importance of computing to the program, the students take an extensive list of related hardware and software computer courses. This forms the common base for ES&C students before they specialize in one of the options. In each year there is a design course that all Guelph Engineering students are required to take and successfully complete before proceeding into the next year of study. As part of the design sequence and other courses, the students develop their skills in communications, management and team dynamics. They also learn how to address ethical, legal and social issues. The design problems increase in the level of complexity and responsibility in appropriate years. The design sequence culminates in a fourth year project that is quite intensive.

Currently, there are seven faculty members in the ES&C program and that number should reach nine by 2001. All faculty members try to expose our students to the research they are engaged in; for example: biomedical systems, autonomous robotics, embedded systems, food and animal technology, Geographic Information Systems, parallel computing, software reliability, real-time systems, computer vision as well as document processing. Engineering is, by its very nature, an applied field and the integral role of the computer in a system is sometimes uniquely defined by the application (e.g., process control, biomedical systems, instrumentation systems, communication networks, computer systems, manufacturing systems, or environmental systems).

3.0 Mechatronics

Mechatronics is an interdisciplinary field of engineering and also a design methodology. The field of mechatronics has been described as an intersection of the engineering areas of control systems, electronic systems, mechanical systems as well as computers. Control theory contributes feedback design and stability analysis. The controller is part of a loop for continuous operation in a particular environment resulting in a need for real-time interfacing for analyzing analog, digital and frequency signals. Mechanical engineering donates design, manufacturing and system dynamics. The study of mechanical systems also involves kinematic and dynamic analysis. Computer science/engineering supplies data acquisition methods and algorithms. Information systems tools are necessary for modeling and simulation, automatic control as well as optimization. Modeling and simulating a system before construction is important in order to reduce costs and anticipate potential problems in the implementation phase. Electronic aspects include the actuators and sensors which help interface the system to the outside world. Electrical areas of study include DC and AC circuit analysis, power as well as semiconductor device analysis. Sensors can be as simple as sonar, touch, thermistor or as complicated as vision. Actuators can include stepper motors, DC and AC motors, servo, hydraulic, pneumatic and possibly other unconventional types. In general, the mechatronics design process is typically iterative, and this is exemplified by multi-disciplinary trade-offs.

There are many systems in the existing world that require a synergy of these expertise areas including systems in automotive, aerospace, medical, materials processing, manufacturing and the consumer products application sectors. Some examples of mechatronic systems include aircraft flight control and navigation systems, automobile electronic fuel injection and anti-brake systems, automated manufacturing equipment (e.g., robots, numerically controlled machinery), as well as smart kitchen and home appliances (e.g. bread machines, washers, dryers, toys). The field of robotics can be considered to be a subfield of mechatronics. The typical components of a robotic system include the actuator, communicator, control computer, end effector, manipulator, power supply as well as sensors (see Figure 1). An excellent example of a common mechatronic system is the photocopy machine. Analog circuits are used to control the lamp, heater and power. Digital circuits control the digital displays and indicator lights. Buttons and switches are used for the user interface. Optical sensors and micro-switches are used to detect the presence or absence of paper as well as the correct positioning of the paper. Encoders also track the motor rotation for the various drums that guide the paper through the machine. The actuators include the servo and stepper motors that load and transport the paper, turn the drum and index the sorter. All of these complex interactions are transparent to the eventual user of the system; typically, a mechatronic design goal for any mechatronic systems.

The life cycle for mechatronic design requires addressing: (1) delivery parameters such as time, cost and medium; (2) reliability issues such as failure rates, materials and tolerances; (3) maintainability, which necessitates modular design; (4) serviceability protocols and methods such as on-board diagnostics, prognostics and again modular design; (5) upgradeability; and (6) disposability processes including recycling and disposal of hazardous materials. A computer-aided prototyping environment should provide the tools necessary for modeling, simulation, project management, design, analysis (as well as synthesis), real-time interface, code generator and embedded processor interface. The key to success for any mechatronic system is to strike a balance between: (i) modeling, analysis, control design, computer simulation of dynamic systems; and (ii) experimental validation of models, analysis and understanding key issues of hardware implementation.

4.0 Our Mechatronics Option

The mechatronics focus in our ES&C program is geared to systems which are the synergistic integration of mechanical, electrical and electronic components that are connected by a control architecture typically embedded in a computer. Our students are exposed in their first two years to the primary disciplines that are necessary as a prerequisite for mechatronics design: mechanics, electronics, control, signal processing and computer science. Senior students are exposed to some intelligent control and artificial intelligence principals but the intent is to leave these areas primarily for graduate study.

As mentioned earlier, each of the options, including Mechatronics, is introduced to the students in their third year of study and entails the student taking four designated courses associated with the option area in their third and fourth years. Currently the Mechatronics option consists of an introductory course that has been offered once, an introductory robotics course which is to be offered for the first time in the winter of 2001, an advanced mechatronics course and an automated manufacturing course. The robotics course will focus on the components of a robotic arm, forward and inverse kinematics, internal and external sensors as well as aspects of programming. The automated manufacturing course will introduce the students to the various facets of the manufacturing enterprise. The plan is to have the advanced mechatronics course focus on complex intelligent electro-mechanical design. Our new robotics lab houses 5 A-255 arms (manufactured by CRS Robotics Corporation in Burlington, ON) which will be used for the introductory robotics course and possibly the manufacturing course. The robotics lab also contains a ping pong table which is used for small scale robot competitions in the introductory mechatronics course. This lab is part of a new addition which became operational in September 2000. The introductory to mechatronics course lab sessions are chiefly conducted in a new electronics lab where the students construct small scale soccer playing robots. The robotics lab is utilized towards the end of the term for robot testing and competition. We are currently investigating funding and space options for a new Computer Integrated Manufacturing facility for the manufacturing course.

It is interesting to note that Mechatronic programs at other engineering schools in N. America are typically situated in Mechanical engineering programs. The textbooks available for Mechatronics fit this mold making it difficult to find an appropriate textbook if a Mechatronics option does not fit into the Mechanical niche. Since our ES&C program is a closer relative to a Systems or Computer engineering program than a Mechanical engineering program, our students have a unique background when entering into our Mechatronics option. This necessitated that our Mechatronics curriculum be different than the standard Mechanical engineering one. The emphasis of an introductory Mechanical engineering offering in Mechatronics is placed on electronics and the computer aspects. In contrast, our students are well grounded in these areas, and therefore more emphasis is placed on the kinematics and dynamics analysis as well as the integration aspects.

5.0 Our Introduction to Mechatronics course

Our "Introduction to Mechatronics" course is offered to third year students in the winter semester. It was offered for the first time in the 2000. At that time, 40 students took the course, with about 25 of them being in third year and the rest being fourth year students. Our introduction course tries to strike a balance between the theoretical (reviewing material covered previously at a deeper level) and the practical.

The objectives of our introductory course are that students who successfully complete this course will be able to do the following: (1) choose electronic, software and/or mechanical components for an intelligent electro-software-mechanical system based on cost, performance, ability to manufacture, complexity, reliability, predictability and scalability; (2) model, analyze, design control, execute computer simulations of dynamic systems, identify architectural features of mechatronic systems - components and interfaces - and justify selections made for each component: mechanical, electrical, computer hardware or software; (3) apply mechatronic design principles to robotic (arm and mobile) systems; (4) troubleshoot and debug complex mechatronic systems and specify the tools necessary to initiate and conduct this effort; and (5) construct and debug experimental prototypes of mechatronic systems using analytically validated models. The lecture material covered in the course includes (1) a review of systems

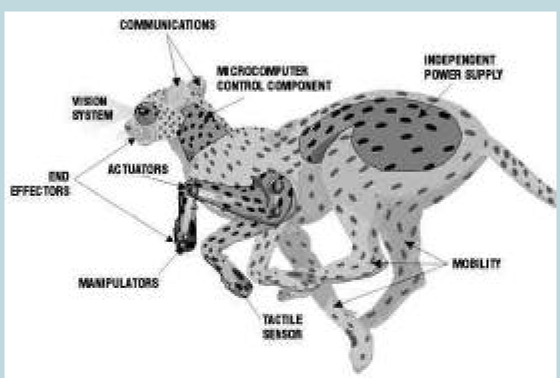

Figure 1: Illustrated are the components of a typical robotic system - which is a type of mechatronics system.

engineering (e.g. modeling, simulation and optimization), (2) an introduction to the theory behind sensors and transducers, (3) the theory behind actuating devices, (4) a review of kinematics, (5) control theory principles, and (6) advanced topics if time permits. The books by Shetty and Kolk [2] and Stadler [3] were chosen as text books. Since the text by Shetty and Kolk [2] did not have adequate assignments and challenges for the students, we plan on using the Stadler text in future years. Four handwritten analytical assignments and three laboratory assignments were assigned. The goal of the laboratory assignments is to properly prepare the students for accomplishing the goal of the project. The analytical assignments were individual efforts while the project and laboratory assignments were done in groups of four.

Mechatronic design requires hands-on exercises in order to instill the necessary concepts; thus, the project and laboratory components. Each laboratory assignment required a physical working demonstration by the students to the teaching assistant (TA) and a submitted report. The three laboratory exercises explored (1) sensing, (2) actuation and (3) control and communications. The laboratory assignments were used to guide the students in activities that were necessary pre-requisites for completing their project: to design a soccer-playing robot (Figure 2). The robot had to meet the specifications as defined by the RoboCup [5] organization, in particular the Small-Size League rules. The students were encouraged to use our machine shop to design and build their robot bases. In addition, the following equipment was provided to the students: a computer workstation, a Handyboard, 4 servo motors, rubber wheels and hubs, a sonar transducer, a RF transmitter and receiver, cabling, headers and shrink tubing, infrared reflective photo sensors, two switches, thermistor, and a hall effect sensor. The equipment was used to construct the robot and conduct the laboratory exercises. The Handyboard [4] is a 68HC11-based microcontroller board with only 32K of static RAM, and is designed for experimental mobile robotics work. It was originally designed at MIT for this purpose. Interactive C was used as the language for developing software for the Handyboard. The host development computer was a Pentium machine running Linux. Linux is an open operating system which made it ideal for tasks like programming the serial interface code for RF communications between the robot and a PC. The first laboratory assignment required the students to use the Handyboard to receive distance and angle readings from 4 infrared sensors (2 types) as well as a sonar sensor. For the second lab assignment, the students had to modify servo motors to function as DC motors. Subsequently, they had to construct and control a differential steering mechanism. The third lab required the students to demonstrate wireless communications between the robot and a PC, trajectory planning and obstacle avoidance.

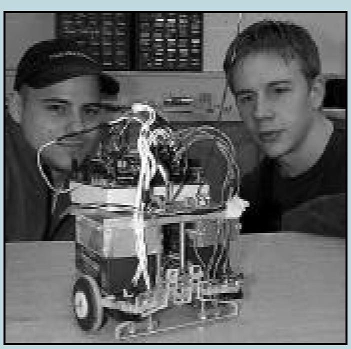

Figure 2: Students Victor Haramina (left), Brian Johnson (right) are shown with their soccer playing robot. Ron Tezuka was also part of the group. This group was one of two groups which designed a kicking device. This group used a solenoid for the kicking device which required a larger battery back.

6.0 Discussion

Given that it was the first time the introductory mechatronics course was run, I think that the course could be considered a success. It is a continual challenge to strongly parallel the analytical aspects (lectures and assignments) with the laboratory and project. The students were excited by the project and spent a considerable amount of time working on the labs and project. This can be verified by all of the groups (10 in all) coming up with a working prototype, mind you, some were definitely far superior to others. As with other courses that involve group work, there is always the problem that some members of the group do more than their share of the work. For future course offerings, it is recommended that the groups consist of only 2 or 3 students at most. Typically, the students spent a lot of time debugging their labs and projects. We were quite fortunate to have a competent technician who proved to be the student's ally in these times of tribulation. Originally, we had acquired a ping pong table to be used for robocup soccer matches. However, the first time offering did not result in any mini World Cup matches but we hope to integrate such competitions in the last two weeks of the term in the future. The experience of building a soccer playing robot provided the opportunity for the students to actually learn and appreciate the concepts that are necessary for an introductory mechatronics course.

The role of the introductory course was to introduce our students to the Mechatronics option. The aspects of group work and a heavy laboratory component will definitely re-occur in the other courses within our Mechatronics option: robotics, manufacturing and advanced mechatronics. As of September 2000, we are very excited by having access to a new robotics laboratory which be used for both the robotics and introductory mechatronics courses in addition to a new electronics laboratory which will also be used for the introductory mechatronics course. Both introductory mechatronics and robotics courses will serve as pre-requisites for the other courses in the option. In January 2001, both introductory courses will be offered, with the robotics course being offered for the first time. We hope to introduce the other two advanced courses within the year.

Readers are invited to look at our web site for the introductory course [1] and provide feedback from industry and other educators about the course and the entire option. As new courses are introduced, course materials will be placed on-line at our School of Engineering web site.

7.0 References

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[2]. Devda Sheety, Richard A. Kolk, "Mechatronic System Design", PWS Publishing, 1997.

[3]. Wolfram Stadler, "Analytical Robotics and Mechatronics", McGraw-Hill, 1995.

[4]. http://el.www.media.mit.edu/groups/el/projects/handy-board/index.html, "Handyboard Home Web Page"

[5]. http://www.robocup.org, RoboCup Official Site.

8.0 Acknowledgments

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About The Authors

John Zelek, Otman Basir and Bob Dony are professors in the ES&C (Engineering Systems and Computing) program at the School of Engineering at the University of Guelph. They were instrumental in getting the ES&C options off the ground. Dr. Zelek took a lead role in the Mechatronics option while Dr. Basir directed the Embedded option and Dr. Dony has molded the Biomedical option. Dr. Zelek's research interests include autonomous robot navigation and dynamic artificial visual perception. Dr. Basir's research interests span sensor fusion and gesture recognition. Dr. Dony's research interests involve medical imaging and image compression.