

## Embedding Design Projects into Multidisciplinary Engineering Education

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**Abstract**—The University of Canterbury has embedded design projects into each of the three professional education years (years 2-4 of the degree) in its new Mechatronics programme. The goal is to create an educational mechanism that links engineering sciences and individual class topics to integrated applications. A series of application-oriented laboratory projects using a Programmable Logic Controller is built into the second-year (1<sup>st</sup> professional year) curriculum. In the third year (2<sup>nd</sup> professional), a mobile robotic system design project encompasses electromechanical design, embedded control, software development and system integration. In the fourth and final year (3<sup>rd</sup> professional), students advance to working on mechatronics research projects that address real-life complex engineering problems facing the industrial sponsors. Embedding design projects progressively into multidisciplinary engineering education has proven to be an effective pedagogy to reinforce students' systems thinking, hands-on abilities, and cross-course linkage.

**Keywords**—*mechatronics, design, project-based education, programmable logic controller, embedded controller, search-and-rescue robots*

### I. INTRODUCTION

Smart products and systems are pervasive in daily life. Design, development, manufacturing and servicing of these products demands increased inter-disciplinary interaction [1]. These trends have driven the demand for mechatronics system design [2, 3], benefitting many industries. However, the approach to providing professional mechatronics education that meets industry needs can vary considerably among higher education institutions in format and outcome.

One approach is to educate undergraduates in traditional disciplines, with mechatronics as a postgraduate degree. Another blends mechatronics education into Mechanical or Electrical Engineering undergraduate degrees. Thus, mechatronics courses might be offered as technical electives in the Mechanical Engineering curriculum, or incorporated as a theme within the degree [4, 5]. In some cases, weekly projects are designed to provide the students with hands-on learning experiences [6]. Electrical Engineering at the University of Twente offers the BSc with one semester of mechatronics-related content and a design project. It also offers a two-year MSc in Mechatronics with Mechanical Engineering [7]. However, increasingly, Mechatronics

degrees are being offered as a distinct multidisciplinary engineering degree, particularly in Europe and Australasia.

The University of Canterbury (UoC) has recently restructured its Mechatronics Engineering honours degree programme into an integrative project-based programme [8], which embeds design projects into a double-weight whole-year course in each of the three professional years from the second to fourth years. This paper discusses the formulation and implementation of design projects relative to mechatronics courses in different professional years.

### II. PROJECT BASED MECHATRONICS EDUCATION

At the University of Canterbury, all engineering students undertake a largely common first year, termed the Intermediate Year. At the conclusion of their Intermediate Year, students apply for admission to the various professional programmes, and are selected based on their preference and performance during that initial year. Professional education in specialized engineering disciplines is delivered from the second year to the fourth year of the four-year education plan. While the common engineering courses in the Intermediate Year are fairly standard, the curriculum development for the remaining three professional education years of the Mechatronics programme proves to be challenging.

#### A. New Mechatronics Degree Structure

After extensive consultation and thorough evaluation, we have taken the approach of project-based mechatronics education in restructuring and design of our new Mechatronics curriculum. Mechatronics students are taught mechatronics-specific courses from the beginning of their professional training in their second year, namely Introduction to Mechatronics Design in the second year, Mechatronics System Design in the third year, and Mechatronics Research Project in the fourth year. Each of these whole-year double-weight design courses is equivalent to two standard-sized courses and covers 20% of the curriculum content for the year. This four-year mechatronics curriculum structure is shown in Figure 1.

#### B. Outcomes

The programme has several key features. First, the level of the design challenge rises with progression through the

programme, and the final result of each design course is a concrete demonstrable project – students have the opportunities to design and build. This allows students to appreciate mechatronics design from an early stage, as well as to see how individual class topics such as circuits and systems and dynamics integrate into the practice of mechatronics design and in creating new systems.

Second, these benefits are obtained because the projects directly interlace with lectures. This concurrency, though causing timetabling difficulties, provides a highly efficient mechanism for enabling students to link textbook knowledge with practical applications and problem solving.

Third, the design projects challenge students to apply knowledge acquired from other relevant courses to their project work. As such, the design projects serve as an integrative knowledge acquisition and application platform.

Finally, in their fourth year students are exposed to real-life complex engineering problems and working ethics through industry sponsorship and mentorship.

System sensing, or a feedback loop, has been integrated into the implementation of the new mechatronics engineering curriculum through a sustained, three-year collaboration between engineering lecturers and academic developers [9]. The data collected each year from the first cohort of students and lecturers were analysed by the academic developers, and results and recommendations fed back to adjust the curriculum, teaching and the assessments to better meet the learning goals. One positive outcome of this new programme is that where earlier graduates indicated they felt a lack of identity, being “neither mechanical nor electrical” engineers, recent mechatronics graduates stated that they feel they have obtained core skill sets in both disciplines.

### III. PLC-BASED MECHATRONICS CONTROL

The second year of the four-year programme lays a broad mechatronics foundation. All courses are compulsory, as shown in Figure 1. The whole-year course “Introduction to Mechatronics Design” introduces students to mechatronics component technologies and the fundamentals of mechatronics systems, including an introduction to mechatronics, sensors and actuators, instrumentation basics, circuit analysis, electrical design, mechanical design, and an introduction to control systems. Two electronics design assignments are carried out using the TINA simulation and layout package, while mechanical design projects use SolidWorks for two design projects.

#### A. PLC as Control Platform

It is always challenging to introduce mechatronics control concepts to students that barely understand the basics of engineering from first-year courses. They have not learnt much about control theory or computer programming. Hence, many mechatronics programmes defer this important part of mechatronics education to later years. Our approach is to expose students to mechatronics system control as early as possible so they are more fundamentally tuned to mechatronics thinking at the later stages. Hence, we reduce the demands on programming skills, but emphasize the inter-relationship of mechatronics component technologies,

namely mechanical design, electrical circuitry, sensors, actuators, instrumentation and control.

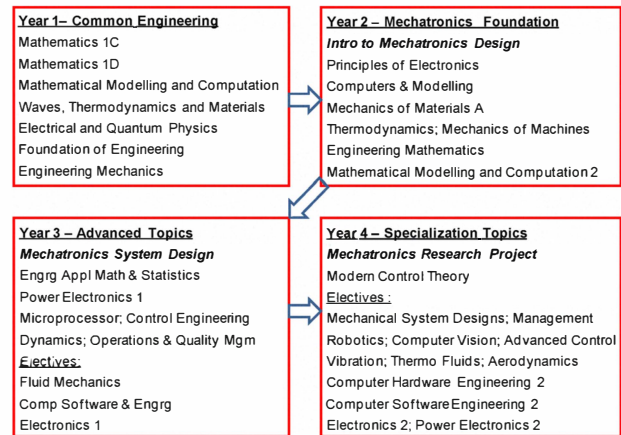


Figure 1. Curriculum structure of the 4-year mechatronics education (honours) programme at the University of Canterbury.

As a result, the lab projects have to be carefully designed so that the hands-on work achieves the objectives of reinforcing students’ mechatronic and system thinking at the proper level. After careful consideration, Programmable Logic Controllers (PLCs) were chosen as the platform for the laboratory projects for “Introduction to Mechatronics Design” because of their ability to accomplish significant tasks with simple graphical programming. Electronics and computer difficulties are minimized, yet the students can readily understand ladder logic diagrams, and profit from a significant design challenge. A PLC-based Computer Control Laboratory was thus established using Omron Sysmac CP1H model processors and CX-Programmer.

#### B. PLC-Based Sensor and Actuator Control

Emphasis is placed on “Learning by Doing” through a series of mechatronics laboratory projects that involve PLC programming, sensors, actuators and control, input and output devices, and data acquisition. Alongside coursework, the design course consists of a series of laboratories in the first semester. Each lab project is a self-contained project exercise addressing a specific application. Students work in pairs to implement a control interface, and design and write control logic using ladder logic diagrams. The following lab projects are carried out in the first semester of the course:

- Introduction to ladder logic
- Control inputs, outputs, and sensors.
- Car washing process automation.
- Water tank level control.
- Stepper motor control.
- DC motor control
- AC motor control

In combination they cover a broad range of basic sensor and actuator concepts, as well as the dynamics, physics and

circuitry needed to use them. They thus provide a strong mechatronics foundation for subsequent years.

### C. PLC-Based Elevator Control

In the second semester, students are asked to develop a fully-functional control system using a PLC to control a 5-storey elevator (10:1 scale) driven by DC motors, as shown in Figure 2. These apparatus were custom built in house, allowing for easy maintenance, modification and expansion.



Figure 2. Elevator control project: the five-storey model elevator (left); and PLC as a control platform (right).

In this project, students use Proportional-Integral-Derivative (PID) control to control the DC motor driving the elevator. Software engineering skills and state-machine design are extensively explored to achieve a realistic elevator control system that handles complex logic. The specially-designed laboratory projects using PLCs put emphasis on the students' problem-solving and hands-on abilities, provoking students to think "mechatronically" and link component technologies into integrated mechatronics systems.

## IV. MOBILE ROBOTIC SYSTEM DESIGN

The Canterbury RoboCup Search and Rescue Robotics design competition spans 12 weeks of the second semester of year 3, and is an integral part of the whole year course "Mechatronics System Design". This project requires students to design and build an autonomous mobile robot capable of quickly locating and gathering three objects (polystyrene cups) in unknown locations within a field of play without any human intervention.

### A. Project Requirements

After an intensive in-house design and build effort, a new Mechatronics Design Laboratory dedicated to the robot design project was established. We chose a low-cost model truck base fitted with the Charmed Labs Qwerk controller [10] as the standard development platform. The laboratory is equipped with 10 such mobile robot platforms. Students

work in teams of three, supervised by two instructors and one senior mechatronics technician. Each project team is provided with one mobile robotic base, and an assortment of simple sensors, servos, and structural raw materials. A supplementary budget of US\$40 may be used to procure additional components. Students are expected to achieving the following learning goals:

- ability to identify the problem requirements;
- ability to generate and evaluate design concepts;
- ability to design and fabricate a manipulator for handling the targets;
- ability to design and fabricate appropriate sensing mechanisms;
- ability to design robotic control software to accomplish the prescribed tasks;
- ability to integrate, test and debug the system; and
- ability to communicate, document, demonstrate and present the design and results.

Thus, projects now begin to focus on broader integration and application of knowledge compared to the prior year.

### B. Concept Design

Tutorials on mechatronics system design techniques and the development platform are provided at the early stages of the project. Simultaneously, the students work in their teams to identify the major system requirements and develop design concepts. The concept generation process typically begins with brainstorming using post-it notes, but often progresses into more structured techniques such as clustering and concept tables. Once students have generated a large number of ideas, they are encouraged to apply qualitative evaluation techniques to select one or two concepts for further development. Again, the evaluation process may begin with an informal examination, but typically progresses to more structured decision methods such as Pugh concept selection or the Analytical Hierarchy Process.

### C. Electromechanical Design

The major electromechanical part of the project is the design and construction of an actuator that collects the objects. Although they all start with the same set of materials and servos, the different student teams have developed an incredibly diverse set of designs for gathering up cups. We have seen a number of variations on pincer-like grippers, several overhead claws, and quite a few designs that use arms to sweep the cups into a scoop. Some teams have opted to use a cup under slight compression as the pickup effector. Other teams have used lassos, or large pads covered in sticky tape. Each of these approaches has its pros and cons, and we find that the students learn a lot from observing how other teams have tackled the same challenge.

The other major component of the robot is the sensors that provide the robot with awareness of its environment. It turns out that the robots need to employ a variety of sensors to locate and retrieve cups while avoiding time-consuming collisions with the walls of the competition arena. Most of the teams make use of infrared and ultrasonic rangefinders to

allow their robot to detect the presence of walls, and to determine the location of the robot relative to the walls. Contact switches are also used to tell the robot when it has driven into a wall. Infrared light sensors configured as “light gates” are commonly used to allow the robot to determine when a cup has been retrieved into a container successfully. Some teams have used the infrared and ultrasonic sensors for detecting cups as well as walls. However, the Qwerk platform supports the use of cameras, and many teams have used a webcam as their primary sensor for target detection. The camera, when coupled with image processing software, is quite effective at locating cups due to its long sensing range and wide field of view compared to the other sensors. It is, however, sensitive to changes in the lighting conditions, which forces the students to carefully consider how to make their design reliable and robust, as well as functional.

To complete the hardware construction, electrical circuits and electrical interfaces are designed to integrate the sensors and actuators with the Qwerk controller, and any additional supporting structures or mechanisms are designed and built. Figure 3 shows an example of a student-designed mobile search-and-rescue robot.

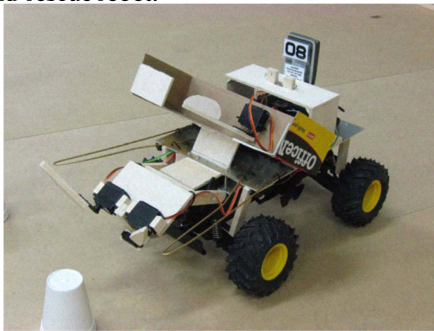


Figure 3. A mobile search-and-rescue robot.

#### D. Software Development and System Integration

There are different ways to design the control software for the robot. Nevertheless, the software typically has the following basic modules or functions in order to accomplish the search and rescue mission:

- Task manager – coordinate all tasks in mission.
- Sensing – detect targets, walls, and successful rescue of a target.
- Navigator – navigate and control the movement of the robot.
- Collector – pick up and place the target.

The software is developed in Java, because that is the language best supported by the Carnegie-Mellon TeRK platform [11] used with the Qwerk.

Because they are working in teams, the students quickly learn the value of developing software in relatively independent and easily testable modules. Minimizing the coupling between modules allows the students to work efficiently without requiring constant input from other team members. At present, there is no robot simulation system in place, and since much of the software is directly dependent

on the TeRK libraries and interaction with the hardware, software testing is typically performed online. However, the image processing functions, being relatively independent of the rest of the robot, and also needing to be fairly robust, are usually extensively tested off-line by batch processing stored collections of images taken using the webcam.

Once all of the hardware and software is tested, debugged and integrated, students can test the system in the competition arena. Different scenarios of target placement and robot home positioning can be tested, and the overall performance and reliability of the robot evaluated. At the climax of the design project a competition is held in which the robot successfully “rescues” the most targets in the shortest amount of time wins.

#### V. INDUSTRY LED MECHATRONICS RESEARCH PROJECTS

The capstone Mechatronics Research Project consists of a year-long mechatronics design exercise. Students can work either in teams (for projects in the Department of Mechanical Engineering) or as individuals (for projects in the Department of Electrical and Computer Engineering). The capstone project provides a meaningful culminating experience that closely resembles the professional projects the students will soon have to take on. Most projects are sponsored by industry, and students are responsible for all aspects, including organization, management (both time and budget), design and prototypes, and final reporting.

##### A. Learning Goals

The research project builds upon the knowledge and skills that students have gained from all of the other engineering courses taken as part of the professional engineering degree. Under the guidance of an academic supervisor, students develop an in-depth understanding of the knowledge and skills necessary for successful implementation of a significant development effort. The capstone project has the following learning goals:

- ability to understand customer’s requirements, formulate research problems, analyse and critically evaluate ideas;
- ability to apply knowledge and skills gained from prior coursework to solve complex engineering problems;
- ability to acquire new knowledge through in-depth research, innovative design and prototyping;
- ability to work with others as a member of a team and external parties;
- ability to communicate technical information orally and in writing; and
- ability to practice sound project management in terms of project schedule, change management, progressive deliverables and milestones, and final deliverables.

Thus, the students learn professional working practice in the context of a realistic engineering problem. They also have the opportunity to develop their professional skills in the areas of leadership, team dynamics, interpersonal

relationships, technical communications, and project management. The project experience enables students to make the transition from academic learning practice to professional practice.

### B. Industry-Led Resesearch

Most mechatronics research projects for the final year students have industrial sponsors. A sponsoring company provides support in terms of funding, materials, technical inputs, project monitoring and alignment. The project team is required to have weekly project meeting with the academic supervisor and the industrial mentor.

To achieve a realistic goal, student teams are challenged to properly scope the level of effort, and seriously consider the resources and time they have available to successfully accomplish project objectives. Almost all mechatronics research projects lead to a prototype or demonstrator. Figure 4 shows a prototype underwater robotic system for shallow water (20 meters) applications, delivered by one project team.

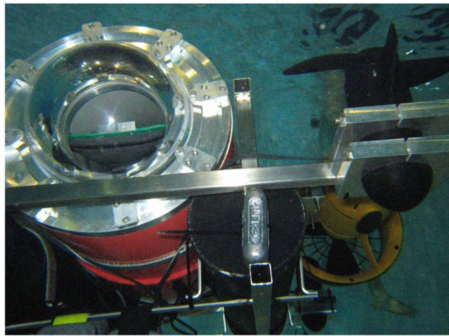


Figure 4. A mechatronics research project developing an autonomous underwater vehicle.

Through this whole-year research project, students have the opportunities to put their mechatronics skills, including mechanics, electronics, and computer control, into practice. They gain valuable experience in a complete project life cycle from understanding project requirements, through the project proposal, conceptualisation, preliminary design, detailed design, prototyping, debugging, testing, to the final project report. At each stage, the industrial sponsor is closely involved. The project proposal needs to be agreed by the sponsor. The preliminary design review and detailed design review are signed off by the sponsor. Such industrial mentorship ensures that the project progresses in the right direction, and is aligned to the customer's needs.

## VI. CONCLUSION

The University of Canterbury has taken a systematic approach to restructuring all three professional years of the mechatronics program. After 3 to 4 years' concerted effort, the Mechatronics Engineering Programme at the University of Canterbury has developed into a premier engineering programme that attracts top students nationwide and overseas. It has grown to an intake of 30 students per year, with room for expansion. The new program puts the focus on hands-on training and critical thinking through laboratory

work and projects. These projects provoke students to think "mechatronically" right from the beginning of their professional education to their senior years. Students have responded positively to the new programme. The graduates are sought after by industry. Further work is needed to monitor the graduates' profiles and industrial acceptance, which will serve as additional feedback in our work toward excellence in mechatronics engineering education.

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