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TEACHING MECHATRONICS IN INDUSTRIAL DESIGN ENGINEERING

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1. Introduction

In recent years, the number of products containing a combination of mechanical and electronic systems has increased enormously. The oldest and largest number of examples can be found in the automotive industry, the average car now has more electric actuators (motors, valves, etc) then ever before. However, the number of mechatronic applications in smaller consumer products is increasing as well. I.e. Cd-players, laundry machines, central heating systems, domestic bread baking machines et cetera. This was the obvious driver for the implementation of mechatronics into the curriculum of Industrial Design Engineering (IDE) at Delft University of Technology (DUT).

1.1 The Faculty of Industrial Design Engineering

Industrial design engineering (IDE) at Delft University of Technology is the largest university-based design course in the world. Since it was founded in 1965, more than 2500 designers have graduated in IDE. Delft is also a pioneer in educational innovation and an important source of research in the field of industrial design engineering.

The curriculum is divided into a Bachelor and a Master phase. During the bachelor's phase, students develop a solid background in engineering and are introduced to the various aspects of product development. These include: manufacturing and engineering techniques; human-product interaction; design; marketing; and, (innovation) management. These, together with the methodical aspects of the process and design skills, are brought together through design projects.

Students of Industrial Design Engineering have a choice of three master's degree courses.

- Integrated Product Design; Covers the whole design and engineering process, integrating all aspects relevant to product development.
- Design for Interaction: Graduates on this course specialise in the analysis and conceptualisation of designs for human product interaction.
- Strategic Product Design; this course emphasises the fuzzy front end of the new product development process (product planning) and also addresses the commercialisation phase.

1.2 Problem definition; Teaching mechatronics at Industrial Design Engineering

Both in third year design projects and in graduation projects, we experienced a lack of system thinking amongst students; when solving design problems, students in Industrial Design Engineering tend to take a visual/design attitude more than an analytical/system thinking attitude. We also experienced a lack of knowledge on the integration of electronics, mechanics and control systems in a smart way. We realized that the existing courses in electronics and product engineering did not provide the students with an integrated approach towards everyday mechatronic problems, we simply had no 'mechatronics course' in the IDE curriculum.

1.3 Towards the id 3411 Mechatronics course

As both courses (one course in product engineering and one course in applied micro-electronics) as such did not allow for an integration of all related aspects in one course, we decided to merge parts of the existing courses and combine this with a course in control systems. Control engineering offers the possibility to define and analyze a broad range of design problems and would strongly enhance system thinking. Merging electronics and mechanics proved to be the least of our problems; both the responsible professors for these courses had an open attitude towards change and saw opportunities for the integration of parts of their course. The largest challenge was to enable students to internalize the combination of control systems, mechanics and electronics. The solution we found was just as simple as effective; we designed a series of four practical exercises using a combination of simulation software (Working Model by Knowledge Revolution Inc. and VisSim by Visual Solutions Inc.) and the 80C51 microcontroller. Due to their real-time visual feedback to the user, both software packages perfectly matched our students learning behaviour.

2. Description of the id 3411 Mechatronics course

The Mechatronics course can be found in the third year of the IDE curriculum (final Bachelor year). The one-semester, 160 hour course consists of 12 sets of lectures (in Dutch), four practical exercises and 116 hours of studying. The lectures provide with an introduction to the various subjects and examples of mechatronic applications. Prior to the examination, there is a special question-and-answer lecture in order to prepare for the tests.

2.1 Course literature

During the course we use one textbook [Bradley, 1991] and a set of college readers. The text book 'Mechatronics' 'identifies the concepts which underpin the mechatronic approach to engineering design and brings together its principal components –sensors and transducers; embedded microprocessors; actuators and drives- to explore their interrelationships' [Bradley, 1991]. In addition to this text, 'Mechatronics' also presents four mechatronic case studies (the Canon EOS camera, fly-by-wire, BA small parts flexible manufacturing system and the Autohelm 800 boat auto-pilot). Although this seems rather a well adapted textbook, the emphasis is more on 'machine engineering design' and electronics than on 'product engineering design'. Already since 1996, we regularly check publisher for more appropriate text books on 'mechatronics in consumer products' but until now this search has not been successful. The main college reader [Dijkstra, 2002] contains; reprints from [Nise, 2002], a chapter on actuators (specifically four-bar and cam mechanisms), electric motors and the manual for the practical exercises.

2.2 Use of e-learning support

WebCT [WebCT, 2002] is the main e-learning tool at our faculty and was introduced during the 2002/'03 course and now consists of the following items: news, course content, examples of former examinations (fully explained), Frequently Asked Questions (FAQ) and tricks and tips. Furthermore, the site contains up-to-date pictures and movies of specific applications of mechatronic systems in consumer products. Until now, the opportunities of this e-learning support system haven't been exploited fully. I.e.; the discussion section is still little used.

2.3 The practical exercises

We defined four practical exercises (four hours each) in order to provide students with some hands-on experience in the application of four-bar mechanisms and control systems. The practical exercises on control engineering enhance understanding the notion of feed-back systems. Next to these practical exercises, we stimulated the students to enrol in the (three day) IDEC robot contest [Jansen, 2003]. This robot contest is build into the IDE curriculum as an elective course and offers the opportunity to get hands-on experience with using electric motors, gearboxes et cetera. (see figure 1).

Figure 1. The IDEC robot contest (Left; 'stop the volcano', Right; 'tower building')

2.3.1 Practical exercise 1

In this exercise student learn how to use 'Working Model' [Knowledge Revolution, 1995]. Working model allows motion simulation and is especially helpful in early design stages when you have to build, test and refine your mechanical designs.

2.3.2 Practical exercise 2

During this exercise, students start building a model of a simple (bi-state) control system (typical Dutch; the climate control of a greenhouse) using VisSim software [Visual Solutions, 2003]. Having experienced the imperfections of this simple control system, they then have to simulate a proportionally controlled electric motor (PM motor)(see figure 2). The specifications of the motor during this exercise are acquired from the real motor used in practical exercise 3. Due to the visual character of the interaction with VisSim, students easily grasp the essence of the simulation. In order to generate an additional learning experience, we lure them into an unrealistic simulation (motor speeds altering from 0-5000 rpm at 160 kHz) and see how they find out this is nonsense. In fact the message is; the simulation software will perfectly tell you how you modelled the world, whether it's realistic or not. So please, don't switch off your own brains…
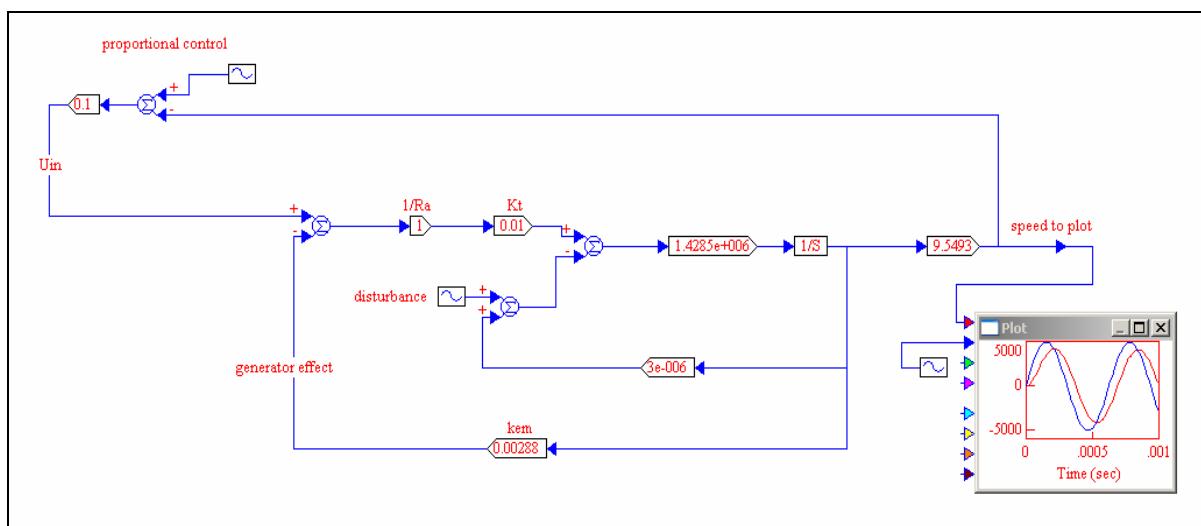

Figure 2. Simulation of an electric motor using VisSim [Visual Solutions, 2003]

2.3.3 Practical exercise 3

Once the students have experienced the computer simulation, they then have to simulate the same system in reality. The set-up consists of an electric engine, a separate power source, PWB for motor control, micro controller (80C51 for duty-cycle control) an opto-coupler to measure engine speed (see figure 3.) The motor is powered using pulse-width-modulation (PWM), different weights can be attached to the motor shaft in order to change the behaviour of the system.
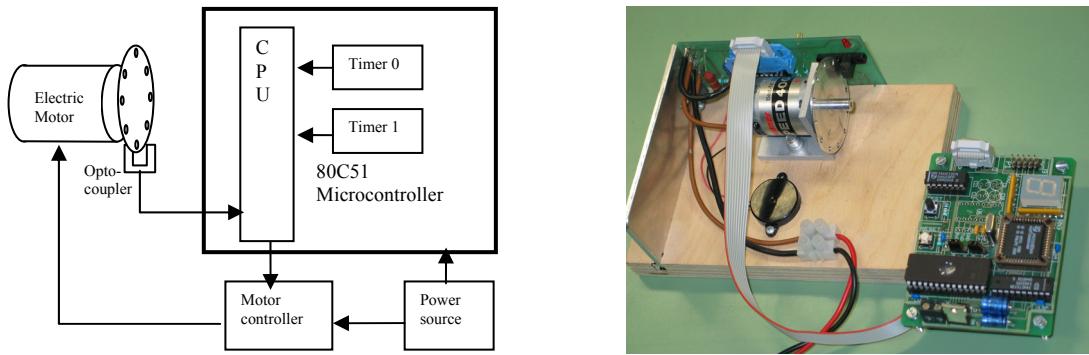

Figure 3. Schematic representation and picture of set-up for practical exercise 3

2.3.4 Practical exercise 4

The final practical exercise takes the students back to the computer and VisSim. We offer the students a realistic design problem (CD speed controller) and an improved motor simulation including speed measurement with adjustable sample rates. The assignment consists of designing and testing a PI-controller.

2.4 Course examination

The examination of the full course is divided into two parts; in the first part, the emphasis is on electronics, the second part emphasis engineering aspects of the course. In the electronics part, the students have to write a technical essay on possible improvements of a domestic appliance by means of electronics. The subject of the essay is published three days before the examination allowing students to gather specific data on the subject. Recent subjects; cooking hood, freezer and electric heater. The assessment of the essay is based upon two criteria; are the improvements electronically well engineered and do the added electronics improve the function of the product, i.e. is it an innovation?
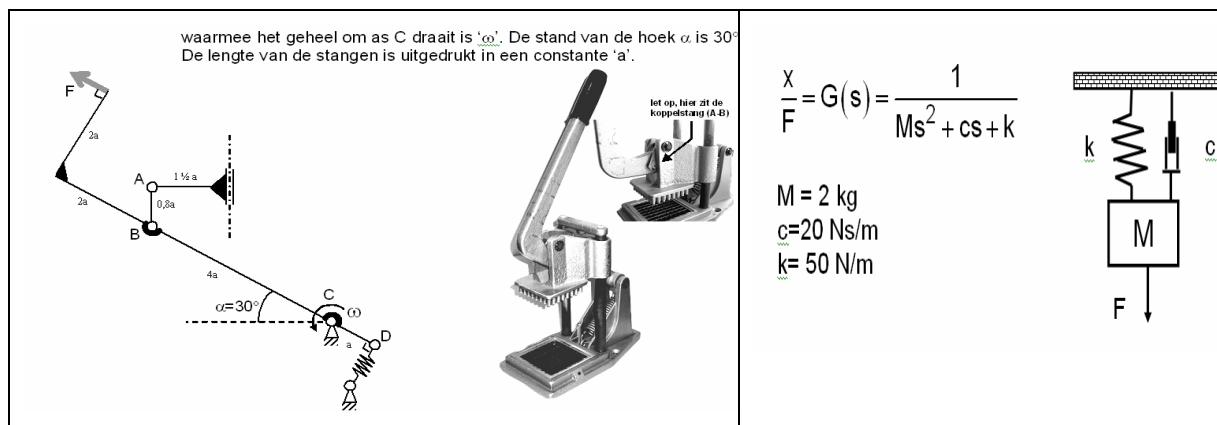
Figure 4. Two examples of questions during the engineering part of the examination (Question on the left: locations of the momentary pole, degrees of freedom, velocity of point A. Question on the right: system response, relative damping, etc)

In the second part of the examination, the emphasis is on testing mechanical/engineering knowledge. It is a straight-forward written question and answer test, consisting of 10 questions (3 hours). Subjects are; four-bar and cam mechanisms, hydraulic, electric and pneumatic actuators, control engineering and motion converters (see figure 4). Students are allowed to use lecture notes, books, et cetera, during both tests.

3. Discussion

3.1 Publications on teaching mechatronics

In literature, significant numbers of publications on teaching mechatronics can be found. Starting as early as the 90's [Carryer, 1995] these mainly emerge from a mechanical of electronical background. Although the significance of teaching mechatronics in product design courses is clear [Salazar, 2000], specific literature in this domain could not be found. From Craig's' [2001] description of the mechatronic process ('a balance between modelling and analysis on the one hand and experimental validation and hardware implementation on the other hand') we realised that we will have to emphasize the analysis and modelling part in the course.

3.2 Course evaluation

In order to improve the overall quality of our education, we perform course evaluations on a regular base. The evaluation consists of a student questionnaire (5 point scale, from - - to + +) and an interview with the professor in charge. Results from the last course evaluation, year 2002/'03 [Bos, 2003] (n=94, 41% of total population) shows a number of improvement opportunities and a number of strong points (see table 1). Based on this evaluation we decided to implement e-learning support (was implemented during the course), up-date the readers and introduce an extra examination exercise in order to stimulate regular studying.

Table 1. Results of course evaluation 2002/'03 [After Bos, 2003]

Course strengths (> 50% of respondents rates + or ++ at remarks stated below	Course weaknesses (>33% of respondents rates – or -- at remarks stated below)
The importance of the course within the curriculum is evident.	The way this course is organised does not encourage regular studying
The rated numbers of study-hours for this course was in conformance with the actual input.	The quality of the course material (text books, course readers) varies strongly.
The teaching staff is enthusiastic about the course and is open to questions/remarks; style of instruction during the practical exercises was seen as supportive.	Students' dedication varies.
The practical exercises enhance the insight into the application of control engineering, student expect to use the provided software in their professional careers.	Students noticed a lack of e-learning support.

3.3 How to move on?

Mechatronics and especially control engineering is tuff-stuff to teach to IDE students. Their ability to design products is developed better then the ability to model and analyse more abstract phenomena. In our course we try to bridge the gap between these two aspects by showing links between abstract models and their applications in real life. Especially the practical exercises prove to be helpful here.
Existing books on mechatronics still don't cover the specific need of our course, they lack the combination of subjects essential in product design. The right mix between product engineering, product electronics and 'a touch of control engineering' simply isn't available (yet)…perhaps we should think of writing a text book ourselves.

The examination of the course is –until now- divided into two separate sessions, each having their specific benefits and drawbacks. A combination of the two sessions would pose a significant load upon the existing teaching duties but definitely would improve the coherence of the course.

Considering the increasing numbers of mechatronic products, we believe this course helps our students to face the challenge they will meet in practice; making good products for people.

Acknowledgement

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