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CDIO-CONCEPT FOR ENGINEERING EDUCATION IN MECHATRONICS – PROJECT TEAMS IN ACTIVE AND INTEGRATED LEARNING

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ABSTRACT

The paper presents significant good Danish experiment results of a developed CDIO-Concept and approach for active and integrated learning in today's engineering education of MSc Degree students, and research results from using IT-Tools for CAE/CAD and dynamic modelling, simulation, analysis, and design of mechatronics solutions with fluid power actuators for motion control of machines and robots. The idea of CDIO-Concept is to take care of that the students are *learning by doing* and *learning while doing* when the students are active to generate new products and solutions by going through the phases from to Conceive, Design, Implement and Operate related to en product design by them self in competition with others. The idea is based on the Danish implementation of a CDIO-Concept. A curriculum at Aalborg University, and Technical University of Denmark, offers courses for Motion Control, Fluid Power within mechatronics design, and advantages as well as challenges are identified and discussed. An IT-tool concept for modelling, simulation and design of mechatronic products and systems is proposed, and results from a Danish mechatronic research program on intelligent motion control.

KEY WORDS

CIDO, Engineering Education, Mechatronics, Project Learning, Motion Control

INTRODUCTION

Companies are facing an increasing global competition on the market and the on-going challenge that customers always increase their needs for capability of products, solutions and machinery. Customers want improved productivity and efficiency – if possible to lower prices and rapid delivery; value for money. The demands focus on extensions of functionality, faster response, operation capability, man-machine interface (MMI), robustness, reliability and safety in use. Today's IT-tool offers both software and hardware for improvement of engineering design and industrial applications. This means companies need professional engineers with qualifications to fit the demands. R&D Mechatronics Teams create mechatronics products, machines and solutions, Figure 1. Mechatronics System Engineering is an emerging integration of mechanical engineering, electrical engineering, control engineering, and smart software engineering.

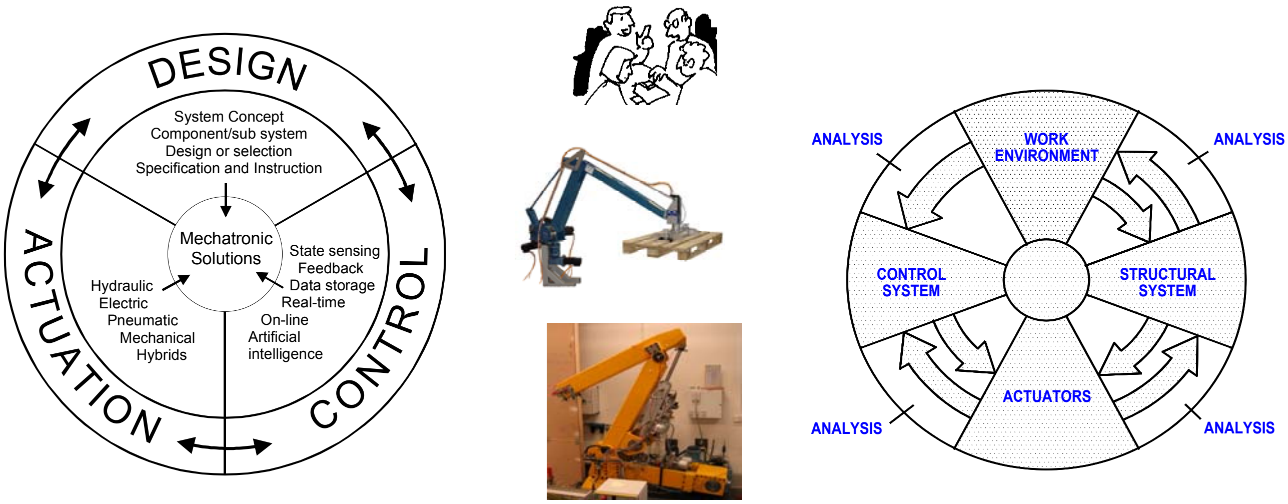

Figure 1 R&D Mechatronics Teams create mechatronics products and solutions

New applications where a mechatronic approach is needed are added each year. The need and demands to the education of engineers in this field are on-going increasing. The challenge is basically to develop the content of the engineering curriculum to strengthen integration of theories and best practice in mechatronic design of novel generations of products and solutions without using extra study time. This paper presents an active and integrated learning approach, which makes it possibly very fast for the MSc student to develop in-depth skills in this important area. The approach is lectures combined with mandatory projects base on active problem-oriented and project-based learning. The idea is based on the Danish implementation of a CDIO-Concept. A complete curriculum at Aalborg University, AAU, and Technical University of Denmark, offers courses for Motion Control, Fluid Power within mechatronics design, and advantages as well as challenges are identified and discussed. An IT-tool concept for modelling, simulation and design of mechatronic products and systems is proposed in this paper. It built on results from a Danish mechatronic research program on intelligent motion control.

CDIO CONCEPT - PROBLEM-ORIENTED AND PROJECT LEARNING

IT-tools for controller design and for intelligent motion control could satisfy customers' needs, requirements and the regulations etc. Mechatronic test facilities with digital controllers for a hydraulic robot, hydraulic cranes and mobile vehicles have been implemented for R&D, and for education of students based on a Danish developed CDIO-Concept, and problem-oriented and project-learning, illustrated in Figure 2, Figure 3, Figure 4, and Figure 1.

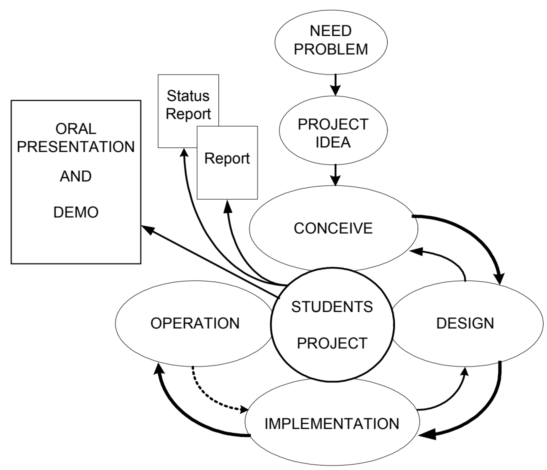

Figure 2 CDIO-Concept (Finn Conrad, 2005)

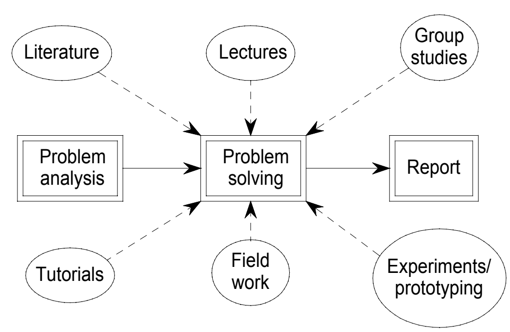

Figure 3 Problem-oriented and project-learning

Such a problem-driven and project-based learning do strengthening of the students' *self-learning competency*. Engineering design can be analysed using the IPD-model, i.e. Integrated Product Development phase model [1].

THE CONTROL ENGINEERING DESIGN TASK

The task of control engineering design can be analysed using the IPD-model illustrated in Figure 4, in order to integrate control theory and design methodology into the design process to create business by turnover.

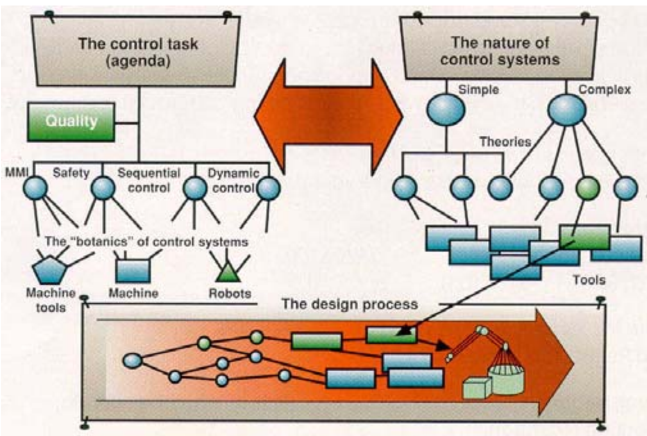

Figure 4 The control engineering design task

The objective of the model is to give an overview and understanding of *the control task* (or agenda), shown to the left in Figure 4, with focus on quality, and *the nature of control systems*, shown to the right. At the bottom of the figure is illustrated *the design process* based on the Integrated Product Development (IPD-model) activities starting with the customers' needs to the very left and ending up with the deliverable product to the very right.
An important part of the engineering knowledge base includes descriptions, models and experiences concerning known products, including controllers, machines, robots etc. In this context, it is named as knowledge on the '*botanics*' of control systems. The control aspects are focused on the areas: Man-Machine Interfaces (MMI), safety, sequential control and dynamic control. As shown, the modelling activity for an actual control task relies on the available theories, methodologies and tools to model and describe the behaviour of the product undertaken in the design process. The IT-tools and laboratory facilities are needed real-time for experimentation, evaluation and validation of control laws and algorithms. Furthermore, a problem-driven and project-based learning framework for strengthening and development of the students/candidates *self-learning competency* is proposed and discussed.

Successful R&D-project business
The designer and/or the team of designers pre-determine the production related costs and hereby the business potential during his and/or the team's decisions in the design phase. The awareness of managing this relationship is very important during the design of products to make a successful business. This is in particular important for enterprises in mechatronics. Use of the IPD-model and available IT-simulation techniques suitable for hardware in the loop simulation and rapid prototyping could improve the design phase and test phase in order to reduce the time to market and total costs leading to a successful business. The design and development of fluid power components and systems by use of smart simulation and IT tools in a concurrent engineering approach following the iterative design concept illustrated in Figure 5 by Conrad [2] and [3]. The driving forces are the designer's innovation, creativity and thinking combined with their knowledge and capability skills to solve the design task.

IT-TOOL CONCEPT FOR CONTROLLER DESIGN

A company's capability of beating the competitors often depends on the ability to shorten the time of a product's development and design phase and to decrease the total design and prototyping costs. Developing a closed-loop control system for fast mechatronic systems involves control design with plant modelling and off-line simulation as well as real-time simulation and hardware-in-the loop (HIL) simulation to verify the controller's functions, robustness and safety in reality.

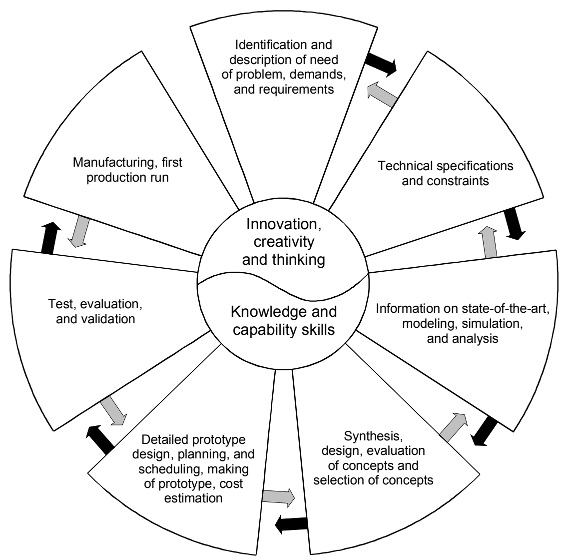

Figure 5 The design process is an iterative on-going engineering driven and controlled process

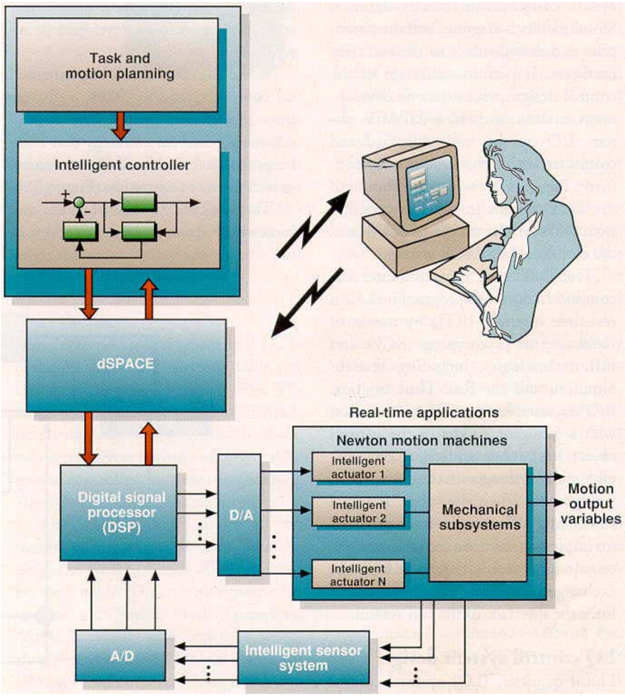

Figure 6 IT-tool concept for control system design

To overcome the disadvantage of the traditional set-up and procedure for controller system design, a novel concept for controller design was developed and implemented at our Department of Mechanical Engineering, DTU. This concept based on use of DSPs and the dSPACE system, as illustrated in Figure 6, is very suitable for intelligent motion control of machines and robots.

For mechatronic products, machines, robots and systems with a controller, this challenge can be undertaken by using a suitable IT-tool concept for controller design based on CACSD (Computer Aided Control System Design) with facility for rapid controller prototyping with HIL simulation capability. A feature is the integrated design and rapid prototyping of controllers targeted at Digital Signal Processors (DSPs) or other embedded systems. The high performance and low cost of today's DSPs together with the use of powerful design and programming software, allows engineers to design controllers faster and with lower cost than traditional "custom" controller board designs. DSPs and Alpha processors are a very suitable hardware of choice for design of controllers utilising the CACSD packages such as Matlab/Simulink, VisSim, Easy5, ACSL, Dymola, Saber and AMESim.

The DSP card that facilitates the computer control is programmed via a Real-Time Interface (RTI) by means of 'Rapid Control Prototyping' (RPC) and 'Hardware In the Loop' (HIL) technologies including Matlab/Simulink and the Real-time Toolbox. The application is running on the real-time hardware the RTI and a virtual instrument panel, COCKPIT enables the user to change parameters and monitor signals, and a TRACE facility that displays the time history of any variable being used by the application.

CDIO EDUCATION IN MECHATRONICS DESIGN

Education both during ordinary graduate studies and through life-long learning becomes still more important. The technological progress is faster than ever and the 'life-time' of a new education is becoming shorter and shorter. In some emerging technology areas the lifetime is less than three years. However, basic skills like mathematics, physics and related technical disciplines are still important as well as skills like communication (written and orally), teamwork, project organization and management are becoming more and more useful.

Bachelor or Master project, where normally only two students work together. Each project group has during their project a supervisor who is a member of the faculty and the supervisor is also an active researcher. The project group requires a room at the university where they can work with their problems in connection with their project, meet their supervisor and solve problems related to the courses/lectures. A typical day for the students is divided into two halves with lectures and one project is carried out at each semester. In their final project (thesis) the students spend all the time on the project work. Normally 6 students work together in a project group except for the tutorials from 8.15 to 12.00 and project time from 12.30 to 16.30. This means that the students during their study are present almost all the time at the university. It is a great advantage that the students have their own room. This greatly facilitates their eagerness to use the teacher during course specific problem solving. The challenges lie in the physical planning and the subsequent demand for office rooms. Each semester has a specific theme and project titles address problems related to this theme. The academic staff and industry make proposals to a particular semester. The proposals are at the higher semesters (graduate) mostly related to the research interest or initiated by the industry. Given a problem at a semester the students first make a problem-analysis, demarcating the project and they make a time and working-plan. After that they do the problem solving by the use of literature, lectures, group studies, tutorials, field-work and experiments. During the project work the students have regular meetings with a supervisor (typically weekly).

During the education in Mechatronics System Engineering has focus on three main areas by AAU

- Design of machines and dynamic analysis.
- Control engineering – including modelling and simulation.
- Electro-technics, including analogue and digital electronics, programming of signal processors and microprocessors and control of electrical motors.

The level within these areas is built up during the different semesters. During the 6th to 8th semesters the courses (50%) are combined with project work (50%). During the 9th semester it is possible to attend project related courses, but generally the 9th and 10th semesters are based only on project work. It is possible to choose between making a short final thesis (10. semester) or an extended final thesis (9. and 10. semester).

6th semester - Project theme: "Design and Optimization of Electro-Hydraulic-Mechanical System". A design task is formulated in detail, based on a working cycle where a payload of approximately 400 kg is to be positioned by a small vehicle. A number of standard components: Frequency converter, gearmotor, hydraulic pumpstation and hydraulic proportional valve are handed out to the students and they must use this in the design task. The design is manufactured and the student projects are compared with respect to: price, weight and efficiency. Project example: The outcome of a typical 6^{th} semester project is shown in Figure 7. The vehicle had to ride on tracks laid out beforehand. The price of the vehicle was derived as the purchasing of components such tooth belt drive, bearings and the hydraulic cylinder. The payload had to be picked in between the rails and hoisted above an obstacle during the travel thus complicating the structural design and requiring two degrees of freedom.

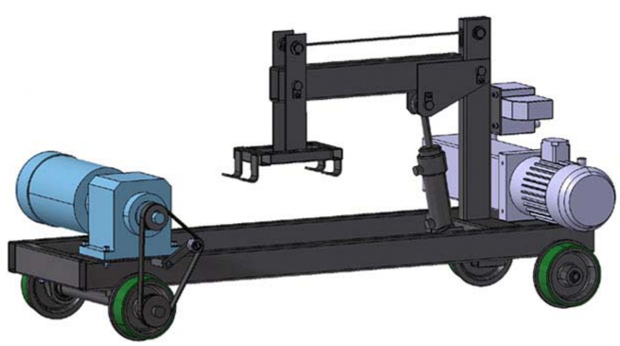

Figure 7 A 3D CAD model of the vehicle build

One may argue that the problem-based approach is almost non-existing in a project as controlled as this one. However, experience shows that the same skills with respect to problem definition and demarcation are just as necessary on a project like this as one with a more broadly formulated initial problem. Also, it is important, to control the projects to a certain degree in order to ensure that certain teaching goals are reached. This balance between the purely problem-based approach and the desire to reach certain levels in different disciplines is one of the greatest challenges in an educational system.

7th semester - Project theme: "Servomechanisms and distributed loads". The project considers an industrial servomechanism with a distributed load. The analysis and design of a position/velocity servo system on the basis of dynamic performance demands is wanted for the system. During the design work both an electrical and a hydraulic servomechanism is elected, and the designed control strategies are implemented digitally.

Project example: A hydraulically driven robot, as shown in Figure 8, was modelled and simulated to test design, implementation and operation of different control algorithms (incl. adaptive and learning). It is a two-degrees-of-freedom rotary arm manipulator with a high-frequency two-stage servovalve controlling each of the two hydraulic cylinders. The simulation model takes into account all nonlinearities and has been experimentally verified. The robot was also used for the experimental evaluation and verification of the designed control algorithms.

Figure 8 The DTU-AAU Hydraulic Test Robot

8th semester - Project theme: "Design and control of power transmission systems". The project considers a power transmission system in a real industrial application, in which the power must be controlled in accordance with a varying consumption situation.

An AC-motor must be part of the transmission system as a power source to a hydraulic-mechanical or an electro-mechanical transmission.

Project example: A small vehicle was designed with a combined steering and traction concept, see Figure 9 Beside the construction of the vehicle the transmission system (using AC motors) and the control system (power converters and control strategy) were to be designed. The control strategy was implemented using a μ-controller and demonstration by operation.

Figure 9 The prototype of designed and build vehicle with AC motor driven traction and steering

9th and 10th semester - The project considers a problem defined in co-operation with a company and Aalborg University. A specialization within a subject area is expected; a subject area in which the student has acquired qualifications on mechatronics. The project may start from a wide range of problems within the mechanical, fluid, electrical, and control engineering. The result of the project ought to be able to form part of or improve existing commercial systems. *Project example*: A 3-degree of freedom spatial servo robot for palette handling was designed based on a typical working cycle defined by a company. The designed, implementation and operation of a 3DOF spatial servo robot for palette handling is shown as an example in Figure 10 created by the MSc students.

Figure 10 A 3 DOF servo robot for palette handling

The project involved development of software for path generation and dynamic simulation used to dimension the mechanical structure, the machine elements, and the servo drive including converter, servomotor and planetary gears. Today do the Department of Mechanical Engineering, DTU and the Department of Mechanical Engineering, Aalborg University both offer each their own programme of specialisation profile in mechatronics for their MSc-students with an emphasis of motion control, intelligent control, analysis and 'best practice' of engineering design.

CONCLUSION AND OUTLOOK

The authors have so far good experience from using the proposed Danish CDIO-Concept for Engineering Education, in particular for a MSc Degree in Mechatronics Design. Promising results are obtained partly from a Danish mechatronic research program (IMCIA) focusing on intelligent motion control as well as results from the Esprit project SWING on IT-tools for rapid prototyping of fluid power components and systems. Examples of AAU and DTU mechatronic test facilities with digital controllers for a hydraulic robot, hydraulic cranes, and vehicles have proven their capability for research and education in mechatronics systems engineering. The controllers have been implemented with digital signal processors (DSPs). The developed IT-tool concept for DSP-based control system design and rapid controller prototyping do utilising the dSPACE System. A challenge of a successful education in mechatronics is the hardware. Cooperate closely with industry companies on projects is a must to assure support funding.

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