Real Time Systems Education at Warsaw University of Technology

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Abstract

The paper describes the contents and the position of real time systems education within the overall study system at the Department of Electronics and Information Technology at Warsaw University of Technology. A course in real time systems is offered for undergraduate students as a part of the computer control profile of study. The paper describes the model of study at the Department, the prerequisite knowledge required for the real time systems course, the course curriculum, and the contents of lectures and laboratory exercises which are mandatory for the students who selected the course.

1. Introduction

Real time system is a system which delivers results on time [1]. The type of the results and the characteristics of time constraints depend on the application domain. The dependence is so strong, that real time systems must always be considered in a perspective of an application domain. Examples of such application domains can be interactive banking systems, process control systems or automatic vehicle guidance systems. The first of the above mentioned domains (banking systems) is characterized by soft real time constraints, which means that the constraints must on average be fulfilled, but occasional delays can be tolerated. The latter two domains are characterized by hard real time constraints, which means that the constraints must always be met, and even an accidental violation can be a source of unacceptable loses and therefore cannot be tolerated.

Real time systems education at Warsaw University of Technology is embedded within the computer control domain, which includes process control systems, discrete manufacturing control and robot control. All those systems are characterized by hard real time constraints. The B. Eng. in Computer Control Systems is a specialist area of study offered for undergraduate students at the Department of Electronics and Information Technology. After receiving the degree, graduated students can continue their education towards M. Eng. in Process Control. The postgraduate study is open also for students that hold their degree in other (than Computer Control) fields of education. Research positions towards the doctoral degree are also available.

The existing study system at the Department of Electronics and Information Technology is currently being restructured and modernized. The changes are aimed at making the system more transparent and easy to manage. The goal of this paper is to describe the modified study system towards B. Eng. and to explain the organization of real time systems education within the domain of computer control. The paper is organized as follows. The general structure of study and the layout of basic courses is described in Section 2. A description of classes attributed specifically to real time systems education is given in Section 3. Special attention is paid to the contents of laboratory exercises. Final remarks and our plans for the future are given in Conclusions.

The following terminology related to the structuring of education is used throughout the paper:

Area of study — a domain of science or technology studied by the students, e.g. Electronics, Information Technology (Computation) or Telecommunication.

Profile of study — a focused sub-area within a selected area of study, e.g. Software Engineering within Information Technology.

Class — basic unit of education visible at the administrative level, e.g. Physics 1, Mathematical Analysis 2 or Introduction to Electronics. Some classes consist of a lecture part, an exercise part, a lab part and a students project.

Course — an informal group of related classes, e.g. a basic course in Mathematics can consist of: Mathematical Analysis 1 and 2, Algebra and Probabilistic Methods. The notion of a course is not defined at the level of the university administration and is used in this paper only for logical structuring of the set of all classes.

2. The model of study

The four year period of study at the Department of Electronics and Information Technology, from the entrance exam to B. Eng. degree, is divided into three consecutive stages (Figure 1):

Stage A (three semesters) is common for all students enrolled to the Department and provides them with a basic knowledge in mathematics, physics, electrical engineering, digital technique and computer programming. The stage includes also a class on Theory of Linear Systems. All classes are mandatory and no options for the students are available. At the end of stage A each student selects a specific area of study, which defines the path of their further education. The choice is between Electronics, Information Technology and Telecommunication.

Stage B (two semesters) is focused on the basic knowledge that all professionals in a selected area of study must have. The program of study is common for all students that selected the same area of study. In case of Information Technology, stage B comprises a supplementary knowledge in mathematics and the basic knowledge in computer architecture, computer networks, software engineering and databases. The stage includes also classes on Real Time Systems and Theory of Control. All classes are mandatory and no options for the students are available. At the end of stage B each student selects a specific profile of study which defines the rest of their education. The choice of profiles within the area of Information Technology is between Software Engineering, Computer Engineering, Decision Support Systems and Computer Control Systems.

Stage C (three semesters) provides the students with a specialist knowledge within a selected profile of study. During the last semester a student should prepare his or her thesis. In case of the Computer Control Systems profile, stage C comprises a theory-oriented course in control and optimization, and technology-oriented classes on Programmable Logic Controllers, Process Automation Techniques and Robotics. The students can also select optional classes from a set of classes offered for other profiles of study or from the advanced classes offered for postgraduate students. Credits assigned to classes of the latter set can be transferred to postgraduate study towards M. Eng. according to the rules of a credit transfer system.

The real time systems education creates neither a separate area nor a profile of study. A course in Real Time Systems is comprised within the following path of education:

common background →
the area of Information Technology →
the profile of Computer Control Systems.

Courses studied along this path are listed in Table 1. The contents of particular courses, the role of the courses and the relation between them, can be described briefly as follows.

Courses offered within the stage A create a basis for further study. Looking at the curriculum from the computer control viewpoint one can note that courses in Electrical Engineering and Digital Techniques introduce the students into the problems of hardware architectures and process interfacing, while a course in Computer Programming prepares them to study the problems of soft-

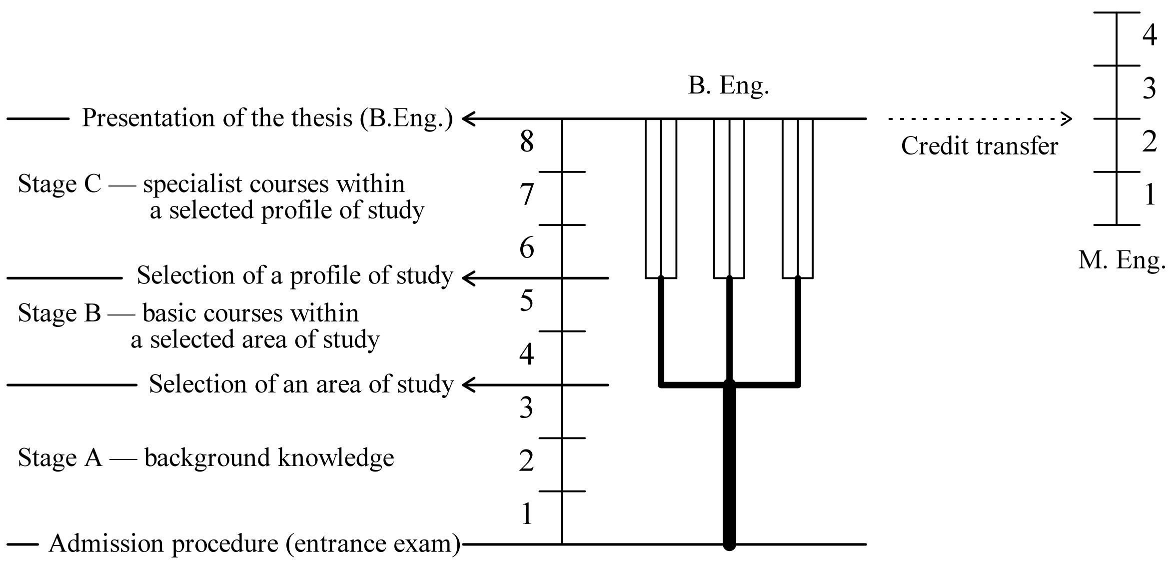

Figure 1. General model of study

ware development. A class on Theory of Linear Systems defines the basic notions of frequency analysis and feedback, which are essential for any control engineer.

Courses comprised within stage B finish the education in mathematics and provide the students with the fundamental knowledge in computation technology. Two classes are particularly important from the computer control viewpoint. A class on Theory of Control explains the algorithmic problems of closed-loop control and a class on Real Time Systems provides a conceptual background for the implementation of control systems. Both classes together compose a necessary introduction to studying Computer Control Systems.

Stage C offers a specialist knowledge in computer control. An extensive course in Control and Optimization Theory consists of a series of classes focused on the algorithmic problems of control, including the analysis and the design of hierarchical and adaptive control. The classes on Programmable Logic Controllers and Process Automation Techniques are focused on the technology of control systems implementation. A class on Robotics can be considered as a complete example of a set of specific control algorithms and their implementation. Projects performed by the students correspond to the work which must be done to prepare B. Eng. thesis.

Table 1. Curriculum in Computer Control

Course	Size [hours]
Stage A (Common)	
Mathematics	300
Physics	105
Electrical Engineering and Electronics	180
Digital Techniques	135
Computer Programming	120
Theory of Linear Systems	60
Stage B (Information Technology)	
Mathematical Methods	105
Computer Architecture and Networks	165
Software Engineering and Databases	225
Real Time Systems	60
Theory of Control	45
Stage C (Computer Control Systems)	
Control and Optimization Theory	240
Programmable Logic Controllers	60
Process Automation Techniques	45
Robotics	60
Students Projects	240
Optional classes	255

Apart of the courses listed in Table 1, the students must also attend a number of non-technical courses in social sciences and foreign languages. The total load of a student ranges 360 hours per semesters (24 hours per week), 300 of which are shown in the table. Still another type of classes is recreation and sport which is mandatory for the students, but does not count to the students load (no credits assigned to this type of classes).

3. Real time systems education

Real time systems provide a platform for the practical implementation of computer control. Therefore a course in this field is a vital part of the overall computer control education. The prerequisite knowledge for such a course includes the following topics:

- electronic circuits and digital techniques (including switching circuits and microcomputer architecture),
- computer programming,
- operating systems and computer networks,
- basics in feedback systems and closed-loop control

All the prerequisite knowledge is offered to the students during stage A. More detailed presentation of the theory of control is given in stage B.

The core knowledge on the subject is offered within the following three classes, which can informally be considered as a course in Real Time Systems:

- Real Time Systems (5th semester, 30 hours of lecture and 30 hours of lab exercises),
- Programmable Logic Controllers (6th semester, 30 hours of lecture and 30 hours of lab exercises),
- Process Automation Techniques (7th semester, 30 hours of lecture and 15 hours of lab exercises).

The course is embedded into the profile of study in Computer Control Systems.

A class on Real Time Systems is common for the entire area of study. A lecture part of the class consists of four sections. The first section defines the basic notions of real time and deadlines, introduces into the problems of task scheduling, and states the problem of system dependability. The second section describes hardware architecture of a control system, including process interfaces and redundancy. The next section, which is the main part of the lecture, goes into the problems of real time operating systems, described from the programmers point of view. This part is based on POSIX standard [2] and uses QNX and OS/9 as examples. The last section describes fieldbus systems exemplified by Profibus [3].

A class on Programmable Logic Controllers is composed of two related parts. The hardware part describes basic types of sensors and actuators, signal standards applied in the industry, the rules for signal conditioning and interfacing, and the architecture of PLC. The software part is focused on the use of IEEE 1131 programming languages [4]: ladder diagrams, function block diagrams and sequential function charts.

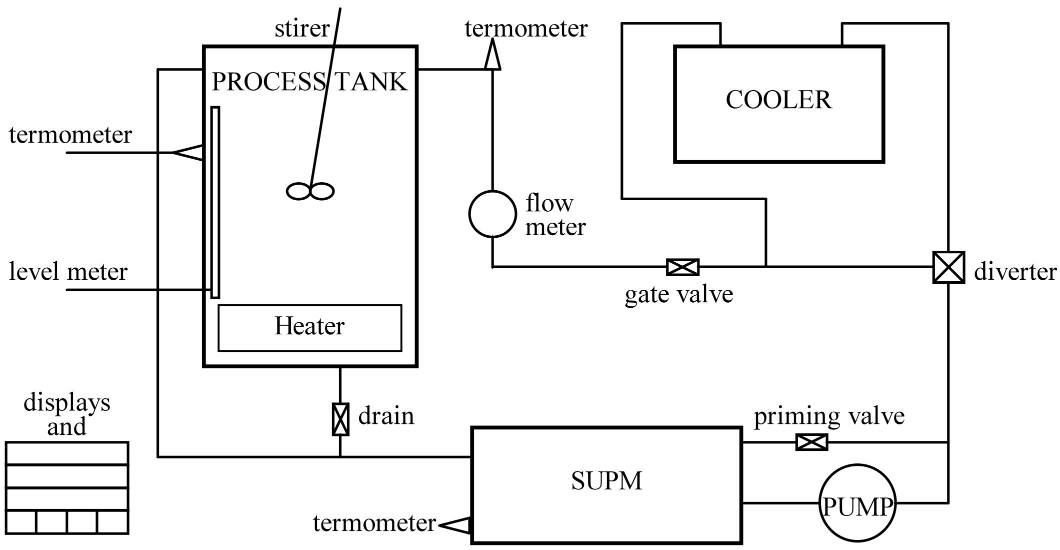

Figure 2. The process rig

A class on Process Automation Techniques addresses basic aspects of the control system design. Topics include: advanced control techniques (adaptive and predictive control), hierarchical multilayered architectures of the control system functionality, modern architectures of distributed control systems (like e.g. TDC 3000), and the techniques used for selecting control system structure.

An important part of the course are laboratory exercises. The lab part of the Real Time Systems class addresses problems related to software development technology, and particularly:

- software development cycle, beginning with requirements specification and finished with the final product validation,
- concurrent task programming with the emphasis placed on cyclic, time dependent execution, and inter-task synchronization and communication.

The equipment used in the laboratory consists of a process model (hardware devices — Figure 2) used as a real-world plant during the exercises, and a network of PC computers under QNX operating system. The process model is composed of two water containers, a heater, a cooler and a pump, all connected together by means of a set of pipes. There are valves installed along the pipes, and the water flow and temperature can be measured in several points. Measurement signals comprise 6 analog values and 1 two-state value. Control signals to the model comprise 3 analog inputs and 8 two-state inputs. The laboratory exercises are organized in the form of a project, developed by a team of 6 to 10 students during six weeks. The initial requirements statement for the students sounds like „Measure and control the state of the plant with appropriate accuracy". The final result is a software running on a network of PC computers and a project documentation. Subsequent exercises correspond to particular phases of the software life cycle. Final mark for the students corresponds to the quality of documentation and to the results of the software validation against the requirements specification.

The lab part of PLC programming demonstrates the use of PLC controllers in typical industrial applications. Topics include:

- basic IEC 1131 programming languages,
- PLC programming devices.

The equipment used in the laboratory consists of two process models (hardware devices) and a set of small PLCs and PLC programming devices from Siemens. One of the process models is composed of two industrial, pneumatic binary manipulators, a transportation system and a buffer arranged within a workcell. The other model is composed of two water tanks, a set of pipes and valves, and a set of measurement instruments, one of which is a CCD camera which measures the water color intensity. The controllers can be attached to the models. A team of students must refine a predefined requirements specification (what does „color intensity" mean ?) and develop programs. The languages used throughout the exercises are ladder diagrams and sequential function charts.

The lab part of Process Automation Techniques is focused on the elements of the system development cycle. No hardware-based process models are used. Instead, the students must simulate a complex process (or a part of a process) using specialized software packages, like Mathlab and Simulink, and synthesize the law of control for the process. In the last step an operator panel based on WinCC software can be interfaced to the process.

The laboratory exercises of the three classes of the Real Time Systems course create a consistent path. In the first of the above labs all characteristics of the system under development — except software structure — are fixed. No design decisions related to the hardware or to the control algorithms are made. The only problem under consideration is the development of software. In the next labs the stress marks are changed. Software development becomes a background task, while the system structure and the control algorithms are addressed. In a real development process the ordering of tasks is usually just the opposite. The advantage of the described succession is, however, that each laboratory exercise can end in a working system. An earlier version of the laboratories, including a description of earlier versions of the hardware and the software, can be found in [5].

The experience from the laboratory exercises has shown that even quite complicated control systems can be implemented. The problem is, however, that the students (like other programmers) tend to work directly in code and to neglect the documentation. The lack of requirements and design specification causes problems during the software integration and testing phase. Great attention must be paid by teachers to force the students to prepare the necessary documentation along with the progress of the development process.

4. Conclusions

Students graduated from Warsaw University of Technology have no problems with finding jobs. So, why any changes to the model and the curriculum of study are needed? There are many reasons of different kind. First of all, the enrollment of students to our Department increased dramatically in the last few years, and the old study system became inefficient — too expensive for the government, and too complicated for the students. Hence, a need for better structuring of study has been developed.

Looking at the curriculum from the computer control point of view, one another problem has arisen. Our graduates work mostly as software engineers in commercial enterprises and need practical skills. Unfortunately, the current profile of computer control is (because of historical reasons) very theoretical and our graduates are better prepared to work as researchers than engineers. One of the main goals of the restructuring is to shift the education from theory to practice. Measures chosen to achieve this goal are a change in class syllabi and an increase of very practical laboratory exercises.

The course in real time systems includes nearly all elements important to this field [7]: process interfacing, real time software and the computer control algorithms. What is definitely missing is safety analysis and assurance. Some elements related to this problem can be found in advanced lectures for postgraduate students, which can be selected as optional classes. Those elements are program verification and proving of the program correctness. A special class in safety analysis, as defined in [6] will be prepared in a near future.

Acknowledgments

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