Education area Control Systems
at
Department of Electrical Engineering
Linköping University

Application for Award for Excellent Quality in Higher Education 2007

dnr 649-183-07

Contact person:
Svante Gunnarsson
+46-13-281747
svante@isy.liu.se

1. Introduction

Background

The education area (Swe: studierektorsområde) and research area (Swe: forskningsområde) **Control Systems** belongs to the Department of Electrical Engineering, Linköping University, Sweden. Thorough information about the area, its courses, and its research activities can be found via the web sites [1] and [2] respectively. The area consists of six professors, two adjunct professors, two associate professors, one lecturer, twelve assistant professors, and approximately 25 PhD students. A list of the teaching staff is given in Appendix A. The undergraduate education is administrated by Director of Studies Anna Hagenblad. A brief description of the overall organization of the engineering education at Linköping University is given in Appendix B.

The area gives a mandatory course in Automatic Control to all MSc programs in engineering (Swe: civilingenjörsprogram) and most of the BSc programs in engineering (Swe: högskoleingenjörsprogram) at campus Valla of Linköping University. This corresponds to approximately 600 – 700 students annually. In addition to that the area offers a large set of elective courses on advanced level. The largest of these courses are:

- Control Theory
- Digital Signal Processing
- Modeling and Simulation
- Digital Control
- Automatic Control Project Course
- Industrial Control Systems
- Automotive Control Systems
- Diagnosis and Supervision
- Vehicle Dynamics and Control

The course Modeling and Simulation was the first one of its kind in Sweden when it was introduced in the eighties, and its concept has been adopted at several universities in Sweden. The three last courses in the list constitute a unique set of courses within the vehicular system area. The elective courses are chosen by the students in competition with a large number of other elective courses in other subjects. The course Automotive Control Systems has also been given four times within the national research and education program Gröna Bilen (Advanced automotive engineering for a sustainable society). The course has had fifty students each time, and a majority of the participants have been students from other Swedish universities (Chalmers University of Technology, etc.)

Overall aims

The overall aim of the education is to make the students as well prepared as possible for their future career as engineers. In order for an engineer to be internationally competitive, the knowledge and skills have to be founded on four cornerstones:

- Solid knowledge in mathematics, natural science and engineering subjects.
- Personal skills giving the ability to apply the knowledge in engineering work
- Ability to work with other persons in teams and to communicate.
- Ability to participate and contribute in the process of conceiving, developing, implementing and operating new products and systems.

The points above formulate the desired learning outcomes for the engineering education, but it is equally important to have an adequately designed organization and infrastructure to facilitate the learning process of the students. All members of the teaching staff have a strong ambition to contribute to a well functioning learning process. An important observation from many years of course evaluations carried out by the students, is that good organization, clear, adequate, and timely information and a positive attitude from the teaching staff are very important factors for an appreciated course and fruitful learning atmosphere.

Evidence of success

It is our strong belief that the area is well qualified for receiving the Award for Excellent Quality in Higher Education 2007. This belief is based on the following fundamental observations.

- The education offered by the area is based on a **solid scientific foundation**. The research within the area is internationally recognized. A large number of text books, on both undergraduate and graduate level have been written.
- The subject contents, **pedagogical methods, and laboratory infrastructure** of the educations map very well to the desired knowledge and skills of a modern engineer, as well as to pedagogical research.
- The area has a **well working organization** with clearly defined routines and responsibilities.

These are considered to be the most important factors contributing to the high reputation that the area has among the students. The reputation is illustrated by the following measurable quantities:

- The students choose our elective courses in large numbers. The courses in the list above have been chosen by approximately 50 – 100 students annually during the last years.

- A large number of students choose to carry out their master's thesis work within the area. During the last ten years approximately 450 master's thesis students have been examined within the area.
- Master's theses examined within the area have received awards of various kinds. Examples of this kind are the prize for best master's thesis within navigation awarded by the organization Radionavigationsnämnden (three times), the best master's thesis during 2004 awarded by the Swedish company SKF, and nomination to the Swedish award Lilla Polhemspriset for 2006.
- The students give the courses high rating in the course evaluations. As a result of that the teaching staff has, during last five year, received approximately 25 letters of recognition from the Dean of The Institute of Technology, distributed over eleven staff members. Such a letter is given to a course that gets rating 4.2 or more on a 1 – 5 scale for course quality. (Approximately 10 % of the courses given within the engineering programs every year receive such a letter.)
- Members of the teaching staff have seven times been nominated to the award Gyllene Moroten ("Teacher of the Year") by the student union within The Institute of Technology.
- Members of the teaching staff have five times received the award Iplom for high course ratings from the student within the program Industrial Engineering and Management.

2. Scientific foundation

Control Systems represents one of the research areas within The Institute of Technology (LiTH) of Linköping University, and it has a very strong and internationally recognized research position. A presentation of the research activities is found via [1] and [2]. The position and strength of the area can be illustrated in several ways. The area has produced a large number of books, journal and conference publications, and the list of Staff members in Appendix A includes links to the personal home page of each staff member, and via that page the publication list for each person can be accessed. The area has a broad perspective in the research and covers both fundamental theoretical issues and industrially relevant problem. In addition to large number of publications the research has resulted in a number of patents. The area has examined approximately 60 PhD students, and the research area Control Systems was one of the areas that were particularly selected within LiTH in the national evaluation of the PhD education carried out by the National Agency for Higher Education (HSV) in 2006, and the area was judged very positively.

The group was for example a central part of the VINNOVA competence centre ISIS (Information Systems for Industrial Control and Supervision) [3], which existed during the years 1996-2006. It can be noted that the specialization Control and Information Systems within the Y- and D-programs (see Section 3) was specially designed as a result of the creation of the competence center. Research projects in close collaboration with the member companies were vital parts of the activities within the center. A large portion of the approximately 450 master's thesis projects that have been carried out during the last ten years have been carried out in collaboration with these companies and with connections to the research projects. Currently the area Control Systems is participating in MOVIII [4] (Modeling, Visualization and Information Integration), which is a Strategic Research Center, funded by SSF (the Swedish Foundation for Strategic Research. A predecessor of MOVIII was VISIMOD [5], which was also supported by SSF. In addition to that the group runs research projects with external research funding from e.g. Swedish Research Council (VR), EU, Energimyndigheten, NFFP, IVSS, etc.

Figure 1: Some of the text books written by staff member. Several of the books are used at the other universities in Sweden and abroad.

The strong research foundation of the group and the connection to engineering education show up in the extensive production of text books in the area. The text book in automatic control [6] was recently released in its fourth edition, and it is used as text book at several universities in Sweden. The text book in control theory, [7], is the only book in Swedish within its field and has also been translated to English [8]. The text book in modeling and simulation [9] is also the only one of its kind in Swedish and is available in English [10]. The text book Automotive Control Systems [11] has almost become a standard reference within its field and is used at several universities around the world. The book Signalbehandling [12] presents modern digital signal processing with a strong emphasis on the use of computer support for problems in this area. Finally, the book [13] presents Matlab as a general and useful engineering tool. In addition a number of text books on graduate level have been written within the group.

3. Organization, quality assurance and infrastructure

Organization

The organization and infrastructure of our courses have several different purposes:

- To aid the examiner in handling and reporting the course results of the students
- To aid the teachers in planning and giving the course
- To aid the students finding information about the course, and minimize the practical obstacles to their learning
- To help the teachers keeping the course material up to date, and use it efficiently when similar material is taught in different courses.

The Department of Electrical Engineering has routines for reporting the course results. These routines have been evolving over the years to a stable and reliable procedure, including how results are transferred and checked between the examiner and the administrative staff. The education area Control Systems also has internal routines for collecting results from laboratory exercises and projects. These routines are documented on local web-pages, and also presented to new teaching assistants in course meetings. Each time a course is given there are a number of well defined roles for the persons involved:

- The examiner is responsible for the course. This includes planning of the schedule, giving lectures, selecting exercises, and designing the exam, etc. The examiner is one of the professors or lecturers.
- The problem solving sessions are supervised by PhD students or teaching assistants (final year MSc students).
- The laboratory exercises are supervised by PhD students or teaching assistants (final year MSc students).
- One PhD student has the role of being “course assistant”. This includes responsibility for the organization of laboratory exercises, to engage supervisors for the laboratory exercises and to arrange a meeting where the examiner meets the persons that will supervise the laboratory exercises and presents the course and the purpose of the laboratory exercise.
- For each laboratory exercise there are two persons responsible for the contents and pedagogical organization. One is from the permanent teaching staff and the other person is one of the PhD students. They are together responsible for the maintenance as well as larger updates.

The basic course in Automatic Control Course is taken by almost all engineering students at the Valla Campus of Linköping University. The course material and the laboratory exercises are more or less the same in these courses, but the lectures give examples from different viewpoints and have different focus for the different student groups.

Quality assurance

The Institute of Technology at Linköping University uses a variety of methods for evaluation and quality assurance, and these methods are hence also relevant and applicable to the education offered by the Control Systems area. In addition to that the area itself has its own routines for assessment of the education quality. The general assessment methods represent a wide range in terms of both method and time scale, and they include, for example, alumni surveys, web-based course evaluations, etc. Some of these methods are primarily intended for the management of the engineering programs, and some of them are also meant for the departments and individual courses. The two most important ones of the general assessment systems are the web-based course evaluations and the follow-up meetings (Swe: årskursråd) that are arranged after the completion of a course.

- The web-based course evaluation is used for all courses given at the Institute of Technology, and consists of a number of questions where the students are asked to give their opinion about the quality of the course, both in terms of course contents and how the course has been carried out. The data from the evaluation are fed back to both the Director of Studies responsible for the course and to the Program Board responsible for the program where the course belongs. For courses that get a too low aggregate rating the Program Board is supposed to present actions that will be taken in order to improve the quality. These actions are formulated in discussion with the Director of Studies. The courses that get an aggregate rating above 4.2 receive a letter from the Dean, where the recognition and appreciation is expressed. This is the kind of letter that was mentioned under "Evidence of success" in Section 1.
- The follow-up meetings are arranged by the student union for the students belonging to one particular engineering program. At these meetings a number of representatives from the students that have taken a particular course meet the examiner responsible for that course for a one hour meeting and discuss the course from different viewpoints according the a predefined form. Minutes are taken and after they have been approved by the examiner they are made available for the Program Board as well as the students.

For the internal quality work within the Control Systems area the results from the assessment described above represent important inputs, and they are used for the continuous development of the courses. In addition there are internal routines that also contribute to the quality assurance process.

- There are weekly meeting where all the members of the area meet. These meetings are used to distribute information and discuss issues of common interest of various topics, where education related questions are among the most common.
- During a course there are weekly meeting where the examiner and the teaching assistants meet and discuss both practical and pedagogical issues. These meetings are very important means to share information and discuss pedagogical issues

related to the topics in a course. The suggested problems for the coming week are also discussed at these occasions.

- After the completion of a course there is a follow-up meeting where the examiner and the teaching assistants meet and summarize the experiences from the course. Inputs to this meeting are the outcome from the exam, the minutes and comments from the follow-up meetings arranged by the students, the results from the web-based course evaluation system, and of course personal experiences. The outcome of the meeting is a list of potential improvements to consider for the next time the course is given.
- There are also annual planning and strategy meetings, and during these meetings education as well as research issues are discussed. Development projects of larger size, like development of new laboratory exercises or purchasing of new equipment, are discussed at these occasions.

Finally, it should be stressed once more that a key component for the quality assurance process is to do careful planning and have well developed routines and responsibilities. This was described in some detail in the section Organization above, but deserves to be emphasized again.

Infrastructure

Since Control Systems is a part of LiTH and the Department of Electrical Engineering the area benefits from the infrastructure on these levels too.

Concerning the physical infrastructure the courses given by Control Systems mainly use facilities in buildings C and B on the campus. Building C contains lecture halls and rooms for problem solving sessions, and the building is used for courses given by all departments. All buildings have wireless LAN, which enables Internet access over the entire campus. The lecture halls have permanently installed equipment to support multimedia presentations during lectures. In building B, which is where the Department of Electrical Engineering is located, there are facilities shared by the entire department but also laboratories run specifically by Control Systems. These laboratories will be described in more detail in Section 6 below. The department manages five rooms equipped with 16 computers each, and these are used extensively for computer supported problem solving sessions, simulation based laboratory exercises, and computer supported examination.

Equally important is the administration and information infrastructure. The information on program level is managed by the administrative staff at Dean's Office, and the course level information is managed by the education area. The overall information infrastructure is well developed with all relevant information available via Internet. Students having spent some time at universities abroad in most cases find the administrative routines and information infrastructure superior at LiTH. To have clear and updated information available via web pages is a cornerstone also at the Department of EE in general and Control Systems in particular. The Control Systems area and the department are often judged positively in this respect by the students in comparison with other departments.

From the viewpoint of a student the physical as well as information infrastructure can be described as follows. All information about a particular course is available in the Study guide, which is found via the home page of The Institute of Technology. From the program plan the student have access to the course plans of all courses within the program. The course plan contains all information that is specified by the regulations, like learning outcome, course contents, literature, etc. From a course plan there is also a link to the course information web-page located within the department. Using the course information the student can find all practical information that is relevant for that particular course. The course information for the courses within the Control Systems area contains, for example, contact information to the teaching staff involved, information about where the literature can be purchased, the schedule for the course including map information about the location of the rooms for lectures and problem solving sessions, etc. The web page also contains a detailed plan for the lectures, including copies of lecture notes, and problem solving sessions, which enables for the students to prepare for lectures and problem solving sessions. The student can also download program and data files that are relevant for problem solving sessions and laboratory exercises. An example of such web-based course information can be found via [20].

4. Leadership and engagement

The area Control Systems consists of the Divisions of Automatic Control and Vehicular Systems led by Professors Lennart Ljung and Lars Nielsen respectively. These roles involve all aspects of the management of the Divisions like the long range research strategy, recruitment of new PhD students, management of research projects, economy, etc. The Director of Studies, Anna Hagenblad, has the administrative responsibility for the undergraduate education, involving the long and short time planning of the courses, budget issues connected to the courses, continuous contacts with the program boards that are responsible for the engineering programs, plus a large number of other issues related to the undergraduate education. All members of the permanent staff as well as the PhD students are involved in both research and undergraduate teaching. In order to obtain a good balance between these activities and a reasonable workload the ambition is to have a planning horizon for the undergraduate education of almost a year. This means that the examiners as well as the PhD students will know at the start of the academic year how the teaching activities are distributed over the year, and do the preparations according to this plan. It is our strong belief that this is one of the factors that contribute to the quality of the education.

Another important factor for the education quality is the personal engagement of all people involved in the education activities. This engagement includes several components, and one of the most important is to maintain an atmosphere and attitude that the undergraduate education is important, and that one should aim for the same high quality as in the research. This includes, for example, giving room and time for discussion of issues related to the undergraduate education. The engagement is of course closely related to how the quality assurance is managed. When, for example, the examiner responsible for a course sees to that there are regular meetings during a course and that there is a follow-up meeting after the course this shows to all persons involved that the undergraduate education is taken seriously.

The engagement in the undergraduate education is also evident by the fact that the Control Systems area is represented in all five Program Boards that are responsible for engineering education at Linköping University. Svante Gunnarsson is chairman of the Program Board for Electrical Engineering, Physics and Mathematics. Inger Klein is vice chairman of the Program Board for Computer Engineering and Media Technology. Torkel Glad, Lars Eriksson and Jacob Roll are members for the Program Boards for Chemistry and Biology, Mechanical Engineering and Design, and Industrial Engineering, Management and Logistic respectively. Lennart Ljung is responsible for the specialization Control and Information Systems within the engineering programs Applied Physics and Electrical Engineering (Y), and Computer Science and Engineering (D) respectively. Lars Nielsen is responsible for the specialization Mechatronics within the Applied Physics and Electrical Engineering (Y) program, and Lars Eriksson is responsible for the specialization Automatic Control within the Mechanical Engineering program. Jacob Roll is responsible for the specialization Communication Systems within the Industrial Engineering and Management program.

5. Learning and examination

The courses offered by Control Systems are based on a variety of approaches for learning and examination, and a brief overview will be given here.

Lectures and problem solving sessions

Lectures and problem solving sessions are key activities in many courses when treating the subject contents. These activities, and in particular the problem solving sessions, can be combined with training in personal skills by encouraging the student's own work, where the teacher mainly is available for answering questions. It is a permanent ambition in all courses to support and encourage the student's own learning. Mathematics is an vital tool in all courses offered by the area, and concepts and methods from for example calculus, linear algebra, and probability are used extensively. Problems of low complexity can often be treated by pen, paper and pocket calculator, but more realistic control problems require computer support in order to be possible to treat. As a consequence of that the group in 1988 introduced computer supported problem solving sessions as a regular part of the learning activities in the courses. This became possible due to the development of PC:s and the software tool Matlab. A natural consequence of the integration of computer support in the problem solving sessions was then to consider computer support also for the final exam. This was introduced on regular basis in the course Digital Signal Processing in 1994, and later extended to the courses Control Theory, Linear Feedback Systems, and Automatic Control Advanced Course M. The development and experiences of the use of computer support has been summarized in [14].

Laboratory exercises

Laboratory exercises are essential components in engineering education in general and in the Control Systems area in particular, and such activities have several aims and purposes in engineering education. One fundamental aim is to strengthen the knowledge in the particular engineering subject, but equally important is to support and develop engineering skills like modeling, experimentation, team work, written and oral communication, etc.

All courses offered by the area contain laboratory exercises of various types. These exercises range from laboratory scale experiments in order to illustrate the fundamental principles to laboratory exercises using real industrial hardware. Several of the laboratory exercises are designed in a student centered fashion, where the responsibility for planning and execution of the tasks is given to the students. This concept is utilized in the mandatory course in Automatic Control as well in several of the elective courses on advanced level. The laboratory Laboteket, see Section 6, has been designed in order to support the student centered learning in connection with laboratory exercises. Section 6 will present two examples of student centered approaches to laboratory exercises in advanced courses. The basic course in Automatic Control, which is taken by all students within the MSc programs, also contains laboratory exercises of this kind. The laboratory exercise **Frequency Domain Compensation** is organized as follows. The instruction for the laboratory exercise contains an extensive set of preparations to be done before the laboratory exercise. One of the things to prepare is a plan for the execution of the experiments. During the laboratory exercise there is a supervisor available during the first hour. During the next two hours the students are supposed to manage the work themselves, and during the fourth hour the supervisor is available to answer questions. After the scheduled session the students are supposed to document their results in a written report, which is handed in to the supervisor no later than one week after the laboratory exercise. The supervisor checks the report and meets the pair of students responsible for the report for a fifteen minutes discussion concerning the report and its results. If the report is not approved at this occasion it has to be revised by the students.

When the complexity of the processes studied in the various courses increases it becomes less realistic to use such processes as physical processes in the laboratory exercises. One possibility is then to use simulation and animation the give impressions of the physical behavior of the process. An example of such a simulation and animation tool is presented in [15].

Projects

Project work is becoming an increasingly important component in engineering education. A main reason is that since the project form is the dominating way to organize development of new products and systems in industry the students should also be trained in project work during the education. The amount of project work in the engineering programs at Linköping University has increased during the last years, and one reason for this is that the university, and in particular the program Applied Physics and Electrical Engineering (Y), is one of the collaborators in the so called CDIO Initiative [16]. An overview of the outcomes of the participation in The CDIO Initiative is given in [22]. This has resulted in the introduction of a set of project courses within the Applied Physics and Electrical Engineering program, and the Control Systems area is involved in two of these courses. The course Engineering Project Y is given during the first semester of the program and the purpose is to give an introduction to the engineering studies and a first experience of project work. Three of the projects included in the course are arranged by the Control Systems area.

In the fourth year of the program the area is responsible for the course Automatic Control Project course, which has become the most popular of the ten different project courses offered during the fourth year. During the last year the course has had approximately 40 – 50 participants. Some of the projects in the course are carried out in cooperation with industry and some are carried out within the department, and in some cases with connections to current research projects. A more detailed description of the project course and some of the projects that have been carried out can be found in [17] and [18]. Examples of projects carried out within the course are “Autonomous underwater vehicle”, “Golf playing industrial robot”, and “Collision avoidance for autonomous vehicle”.

Problem based learning

The idea behind Problem Based Learning, PBL, is to let the students discuss situations relevant to their future profession as a starting point for their learning. This leads to several advantages for the students and their learning:

- The students may see the big picture of why a particular course is relevant to their future profession
- Each individual student can identify what he or she already know within the subject – and what he or she need to study more.
- The discussion around how to solve a particular problem will deepen the understanding of the students and bring up several different ways of attack.
- In discussing a situation, different subjects needed to solve the problem are integrated.

Since 1995, the program in Information Technology has been based on PBL. The Control Systems group is involved in two cross-disciplinary courses, Real Time Process Control and Linear Feedback Systems. The contents, from a control perspective, correspond to the basic Automatic Control Course, which is integrated with aspects from real time processes, as well as supported with mathematics. Teachers from Computer Science and Mathematics, respectively, work together with teachers form Control Systems in these courses. The courses have been successful in integrating the different subjects, and are often mentioned as good examples of how this can be done (both by students and teachers). As a positive side effect, the experiences from PBL have helped the teachers focus on student activation also in other courses. Some experiences from using PBL in teaching control were presented in [19].

6. Laboratory facilities

Laboteket

Most of the laboratory exercises within the courses given by the area are carried out in the laboratory Laboteket. The name Labotek is formed by the Swedish words for laboratory (**labo**ratorium) and library (biblio**tek**), and the design of this facility was based on the idea to combine the traditional laboratory with some of the fundamental features related to a library, i.e. a place used to search for new knowledge and a place that is available almost any time of the day.

Figure 2: One of the areas in Laboteket.

The facility consists of three areas connected in an open architecture with common areas for preparations and discussions. One of the areas is mainly used for laboratory exercises in the basic control courses, and it is equipped with PC computers and interfaces for connecting laboratory processes. The implementation of the control systems is done using the software LabView. The second area, which is used in, for example, Control Theory, Modeling and Simulation, and Digital Signal Processing is equipped with PC computers and so called dSpace interfaces. This enables to structure and design control systems in Simulink and use the code generation feature to obtain en executable program code to be run on the dSpace processor. This feature is for example utilized for design and implementation of multivariable control systems in the Control Theory course.

Figure 3: The area in Laboteket hosting the “Lego factories”.

The third area in Laboteket is dedicated for laboratory exercises in a particular area in control denoted sequential control. To illustrate this principle the laboratory exercises are carried out using computer controlled “factories” producing cars out of Lego parts. See Figure 3. A complete factory consists of two parts, and, in addition to have each part working properly, the two parts have to communicate in order to have the entire plant working. The first generation of Lego factories were built in 1982 and the mechanical design and as well as the pedagogical ideas have been refined over the years.

Pedagogical ideas using Laboteket

The laboratory facility Laboteket is not only a modern and well equipped workspace for various aspects in control but also an environment that enables alternative ways to arrange and examine laboratory exercises. It allows more student centered activities where the students are encouraged to take more responsibility for the planning and execution of the laboratory exercise. In this section some examples will be given of how this is exploited.

The laboratory exercise in **Sequential Control** is arranged as follows. Each half, part A and B respectively, of a factory is managed by a group of two students. The laboratory exercise runs during one week and starts with an introduction and ends with the examination. Between these occasions the students plan themselves when to do the work. During the introduction the students get an introduction to how the factories work and which software tools that will be used. They are also given a requirement specification describing what requirements the final control program has to fulfill. While the students are solving the task there is support available via the web page where the students can report technical problems and ask questions. At the time for the examination the students are supposed to have designed and implemented a control program such that the requirement specification can be verified. The final test in the examination to verify that the students have understood the problem and their solution is that a fault is introduced in either the factory itself or in the control program. The students then have 30 minutes to isolate and correct to fault.

Another example of how Laboteket is used is a laboratory exercise in **System Identification** in the course Modeling and Simulation. System Identification deals with the problem of constructing mathematical models of dynamical systems using measured data. Identifying a real world system involves two main steps, data collection and model estimation respectively, and this has influenced the design of this laboratory exercise. For each student group there is a scheduled occasion in Laboteket when the data collection is supposed to be done. This is done with a supervisor available. After data have been collected the students decide when to do the estimation and validation of the model, and also document the results in a written report. In case it turns out to be necessary the students can go back to Laboteket at later occasions and collect more data. The report is checked by the supervisor and sometimes iterated before it can be approved.

Approaches similar to the ones described above are also used in other courses. The overall idea is to give the students the responsibility for the planning and execution of the laboratory exercises, and benefit from that fact that Laboteket is available at (almost) any time of the day. A more thorough description of the underlying ideas and experiences are presented in [21].

Engine laboratory

As a complement to Laboteket the area also has laboratory facilities equipped with real industrial hardware. The most important is the engine laboratory equipped with two turbo charged engines, together with an advanced control and measurement system. The laboratory is used for education as well as research purposes.

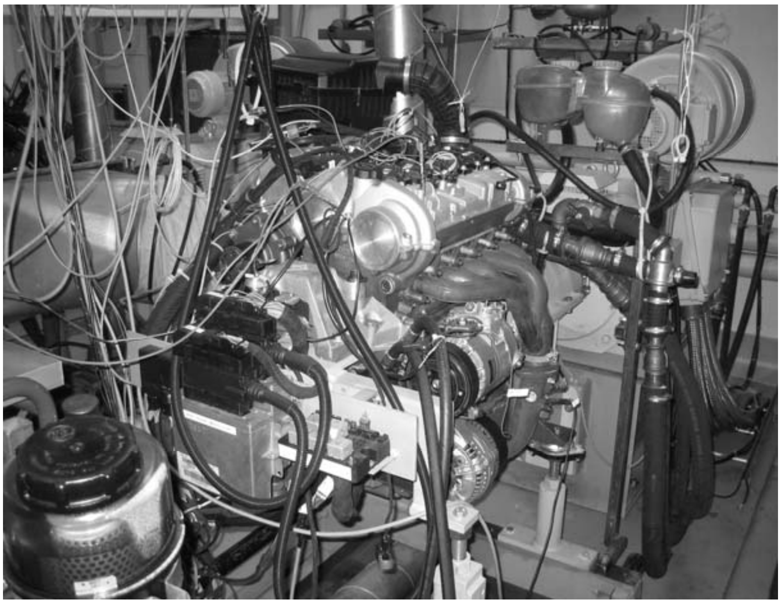

Figure 4: The engine laboratory

The engine laboratory has two engine test stands suited for testing passenger car engines. Both test stands are equipped with modern asynchronous machines which can act both as a drive and a load to the engines. The test stands give the possibility to run steady state and dynamic tests, with torque rise-times less than 10 milliseconds, and for measuring purposes there is a data acquisition system consisting of a VXI mainframe and a PC. The VXI mainframe is fitted with a fast 8 channel digitizer + DSP capable of anti-alias protected sampling up to 196 kHz/ch and a slower module more suited for stationary measurement of up to 64 channels of combined voltage, temperature, current and frequency input/outputs. The slower module is also capable of closed loop control. Most of the experiments concern in-cylinder pressure, ion-current, charger/manifold pressure and temperature, engine speed and torque, lambda, turbo charger speed, etc.

In the engineering education it is used for laboratory exercises in e.g. the course Automotive Control System within both the regular engineering programs and in the national education program Gröna Bilen, which was mentioned in Section 1. Also these laboratory exercises are designed to emphasize the student's own responsibilities. The exercises require careful planning and as a first step the students prepare a plan for the experiments that will be carried out. The plan has to be approved by the supervisor before the experiment can be made. The outcomes of the modeling and measurements are then documented in a written report.

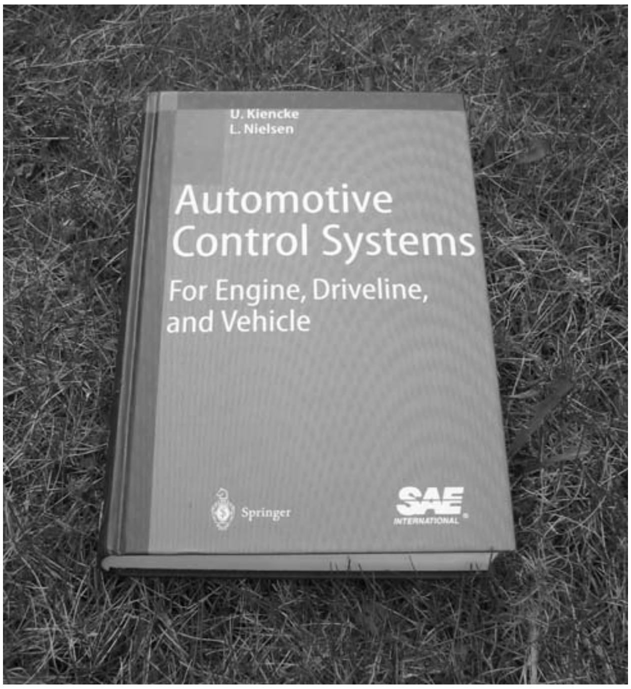

Figure 5. The text book in Automotive Control Systems

7. Student achievements

As mentioned in Section 1 the overall goal of the engineering education is to make the students as well prepared as possible for their future career as engineers. The assessment of how well this goal is fulfilled hence implies to evaluate how well the students perform by the end of the education and as engineers. We will here summarize some evidences for the conclusion that the education offered by the area Control Systems fulfills this goal in an excellent way.

- In the Automatic Control Project Course during the last year the students carry out advanced large scale development projects using industry like work methods. In many cases these projects are carried out in cooperation with industry.
- A large number (450 students during the last ten years) of students carry out the master's thesis project within the Control Systems area. A vast majority of these master's theses are carried out in industry. In many cases the master's thesis has led to permanent employment at the company where the work has been carried out.
- Several master's theses have led to awards, some master's theses that have led to the foundation of new businesses.

It can also be noted that engineers who have graduated from Linköping University in general have high reputation within Swedish industry. This is supported by the fact that Teknikföretagen (The Association of Swedish Engineering Industries) will give the engineering program Applied Physics and Electrical Engineering (Y) the award "Engineering program of the year" for 2007. The majority of the students taking the courses offered by Control Systems and doing the master's thesis within the area belong to that program.

8. Conclusions

The Excellent Quality of the education offered by the area Control Systems rely on a number of **means for success** that together contribute to the overall performance.

- The first is the clear **view of the aim of the engineering education** and the knowledge and skills that are needed.
- A second factor is the **solid scientific foundation**, represented by a large number of books, numerous journal and conference publications, patents, and successful research projects.
- The third factor is a **well developed organization and a positive attitude** where the aim is to support the students in their learning process. This involves for example careful planning and organization of courses, lectures, problem solving sessions, etc.
- Another factor is to use **pedagogical methods** that are in agreement with the overall aims for the engineering education, and combine these methods with **modern laboratory infrastructure and equipment**.

References

[1] http://www.control.isy.liu.se/
[2] http://www.vehicular.isy.liu.se/
[3] http://www.control.isy.liu.se/isis/
[4] http://www.moviii.liu.se/
[5] http://www.ida.liu.se/zope/portals/visimod/
[6] T.Glad och L.Ljung. Reglerteknik. Grundläggande teori. Fjärde upplagan. Studentlitteratur, Lund, 2006.
[7] T.Glad och L.Ljung. Reglerteori. Flervariabla och olinjära metoder. Andra upplagan. Studentlitteratur, Lund, 2003
[8] T.Glad och L.Ljung. Control Theory. Multivariable and Nonlinear Methods. Taylor&Francis, 2000.
[9] L.Ljung och T.Glad. Modellbygge och Simulering. Andra upplagan. Studentlittertur, Lund, 2004.
[10] L.Ljung och T.Glad. Modeling of Dynamic Systems. Prentice Hall, 1994.
[11] U.von Kiencke and L.Nielsen. Automotive Control Systems. 2nd edition Springer Verlag, 2005.
[12] F.Gustafsson, L.Ljung, and M.Millnert. Signalbehandling. Studentlitteratur, Lund, 2001.
[13] F.Gustafsson and N.Bergman. Matlab for Engineers Explained. Springer Verlag, 2003.
[14] S.Gunnarsson and M.Millnert. Computer supported control education from a Linköping perspective. In 4th IFAC Symposium on Advances in Control Education, pages 45--48, Istanbul, Turkey, 1997.
[15] M.Andersson, S.Gunnarsson, T.Glad, and M.Norrlöf. A simulation and animation tool for studying multivariable control. In 15th IFAC World Congress, Barcelona, Spain, July 2002.
[16] http://www.cdio.org/index.html
[17] M.Enqvist, S.Gunnarsson, M.Norrlöf, E.Wernholt, and A.Hansson. The CDIO Initiative from an automatic control project course perspective. In 16th IFAC World Congress, Prague, Czech Republic, July 2005.
[18] Rickard Karlsson, David Törnqvist, Anders Hansson, and Svante Gunnarsson. Automatic control project course: A positioning and control application for an unmanned aerial vehicle. World Transactions on Engineering and technology Education, 5(2), 2006.
[19] Anna Hagenblad and Inger Klein. Teaching control theory using problem based learning. In 12th EAEEIE Annual Conference on Innovations in Education for Electrical and Information Engineering, Nancy, France, May 2001.
[20] Course information for the course Automatic Control (In Swedish). http://www.control.isy.liu.se/student/tsrt12/
[21] Tomas McKelvey. Laboteket. Ett laborationskoncept i riktning mot ett ökat studentansvar för lärandet. NyIng report No. 7. LiTH-ISY-R-2096. 1999.
[22] S.Gunnarsson, K.F. Berggren, T.Svensson, and I.Wiklund. Redesign of the Applied Physics and Electrical Engineering (Y) program according to (CDIO) In 33rd SEFI Annual Conference on Engineering Education, Ankara, Turkey, September 2005.

Appendix A: Teaching Staff

Teaching staff with permanent positions:

- Lennart Ljung, professor, http://www.control.isy.liu.se/~ljung/
- Torkel Glad, professor, http://www.control.isy.liu.se/~torkel/
- Lars Nielsen, professor, http://www.vehicular.isy.liu.se/Staff/Employee/lars.html
- Fredrik Gustafsson, professor, http://www.control.isy.liu.se/~fredrik/
- Svante Gunnarsson, professor, http://www.control.isy.liu.se/~svante/
- Anders Hansson, professor, http://www.control.isy.liu.se/~hansson/
- Inger Klein, associate professor (Swe: lektor), http://www.control.isy.liu.se/~inger/
- Lars Eriksson, associate professor (Swe: lektor), http://www.vehicular.isy.liu.se/Staff/Employee/larer.html
- Anna Hagenblad, lecturer (Swe: adjunkt) , http://www.control.isy.liu.se/~annah/

Adjunct professors:

- Anders Helmersson, http://www.control.isy.liu.se/~andersh/
- Alf Isaksson, http://www.control.isy.liu.se/staff/default.html?usname=alf

Assistant professors (Swe: forskarassistent):

- Rickard Karlsson, http://www.control.isy.liu.se/~rickard/
- Johan Löfberg, http://www.control.isy.liu.se/~johanl/
- Mikael Norrlöf, http://www.control.isy.liu.se/~mino/
- Jacob Roll, http://www.control.isy.liu.se/~roll/
- Thomas Schön, http://www.control.isy.liu.se/~schon/
- Martin Enqvist, http://www.control.isy.liu.se/~maren/
- Ragnar Wallin, http://www.control.isy.liu.se/~ragnarw/
- Erik Frisk, http://www.vehicular.isy.liu.se/Staff/Employee/frisk.html
- Jan Åslund, http://www.vehicular.isy.liu.se/Staff/Employee/jaasl.html
- Mattias Krysander, http://www.vehicular.isy.liu.se/Staff/Employee/matkr.html

Assistant professors (Swe: adjungerad lektor):

- Fredrik Gunnarsson, http://www.control.isy.liu.se/~fred/
- Mattias Nyberg, http://www.vehicular.isy.liu.se/Staff/Employee/matny.html

Appendix B: Organization

In order to describe the place of the education area Control Systems in the organization of Linköping University a brief summary of the structure will be given:

Linköping University consists of four units:

- **Linköping Institute of Technology (LiTH) (**Faculty of Science and Engineering)
- Faculty of Arts and Sciences
- Faculty of Health Sciences
- Faculty of Educational Sciences

Linköping Institute of Technology (LiTH) has seven departments:

- **Electrical Engineering (ISY)**
- Biomedical Engineering (IMT)
- Management and Engineering (IEI)
- Computer and Information Science (IDA)
- Physics, Chemistry and Biology (IFM)
- Science and Technology (ITN)
- Mathematics (MAI)

The Department of Electrical Engineering is organized in four research and education areas:

- **Control Systems**
- Image Processing
- Electronics
- Telecommunication

The engineering education within LiTH is organized in programs. The educational programs are managed by five Program Boards in which the programs are organized according to the main subjects in the programs. The Program Boards are:

- Electrical Engineering, Physics and Mathematics
- Industrial Engineering, Management and Logistics
- Mechanical Engineering and Design
- Chemistry, Biology and Biotechnology
- Computer Engineering and Media

The program boards are formed by faculty members from several departments, representatives from industry, and students. The program boards and the departments hence forms a matrix organization, where the program boards “purchases” courses from the departments which act as a “supplier” of undergraduate courses. An education area, like Control Systems, will therefore have regular contacts with the program boards, via the Director of Studies.