Activity Report: Automatic Control 1997

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Activity Report

Automatic Control

1997

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The report is edited by Eva Dagnegård and Per Hagander

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1. Introduction

This report covers the activities at the Department of Automatic Control at Lund Institute of Technology (LTH) from January 1 to December 31, 1997.

The budget for 1997 was 23 MSEK, which is a slight increase compared to last year. The proportion coming from the University is reduced from 53% last year to 43% this year.

One PhD thesis by Karl Henrik Johansson were defended, which brings the total number of PhDs graduating from our department to 48. Three Lic Tech theses by Lennart Andersson, Johan Eker, and Charlotta Johnsson were completed. Four new PhD students have been admitted during the year: Anna Delfin, Sven Hedlund, Mikael Petersson, and Lars Malcolm Pedersen.

Jan Sternby was appointed adjunct professor (20%) in July. After his PhD at the department in 1977 he left for industry in 1980, and he is currently working in the Therapy Research group at Gambro AB in Lund. He has spent 11 years as adjunct professor of automatic control at Luleå Technical University.

In the civ.ing. program we now have eight courses. The total number of students that finished the courses was 596, and 20 students completed their master theses. The total teaching effort corresponds to about 110 full-year equivalents.

A new Master's program in Automatic Control has been started. This program consists of one year of course work and a thesis. The first students were admitted this year. A new course, Project in Control, is a part of the program. The course is developed by Jan Sternby.

The effort to improve the control laboratory has continued. New computers, new laboratory processes, and new software have been introduced. A substantial effort has also been devoted to development

of new man-machine interfaces for laboratory experiments in the basic courses. New computer-based teaching tools have also been explored.

Research has continued in our established areas: adaptive and robust control, computer-aided control engineering with applications in robotics, power systems, and biotechnology.

Several members of the department have received national and international awards during the year. Three highlights were that Tore Hägglund recieved an award from the *Innovation Cup*, that Anders Rantzer received a Junior Individual Grant from the Foundation for Strategic Research, and that Karl Johan Åström was elected Foreign Member of the Russian Academy of Natural Sciences.

During two weeks in August we had a course in Dynamics and Control,

Karl Johan Åström demonstrates a four-wheel bicycle specially built for the BEST course.

arranged in cooperation with BEST (Board of European Students of Technology). Twenty students from all over Europe studied the basics of control, exemplified by special bicycles.

In August we also organized the "Real-time Week in Lund" (Real-tidsveckan i Lund). The event contained three parts: the official inauguration day for ARTES, an SSF-funded national research network and graduate school on real-time systems; a one-day tutorial on real-time systems given by Prof John Stankovic from University of Virginia; and SNART 97, the Swedish conference on Real-Time Systems containing two days of presentations, a poster session, and an industry exhibition. The conference was a great success with around 170 participants, 39 papers, and 11 industries participating in the exhibition.

Our retrospect this year, in Chapter 7, describes the teaching and research that the department has performed in the area of real-time systems over the years. There have been strong couplings between control and computing from the very beginning of the fields. Today it is important that a control engineer, in addition to control theory, masters both digital computers and real-time systems.

Some statistics of our five year research output is given in the table below. Notice that the entry 95-96 covers a period of 1.5 years.

	92/93	93/94	94/95	95-96	97	Sum
Books	1	0	2	1	2	6
Papers	19	18	17	30	15	99
Conference papers	26	29	24	71	45	195
PhD theses	2	1	3	3	1	10
Licentiate theses	0	0	0	2	3	5
Master theses	14	34	23	40	18	129
Internal reports	16	16	15	18	11	76

Acknowledgements

We want to thank our sponsors, Swedish National Board for Industrial and Technical Development (NUTEK), Swedish Research Council for Engineering Sciences (TFR), Swedish Natural Science Research

Council (NFR), Swedish Medical Research Council (MFR), MISTRA, Sydkraft AB, Elforsk, Pharmacia & Upjohn, Swedish Institute of Applied Mathematics (ITM), and the European Council for their support to our projects.

2. Internet Services

World Wide Web

Our homepage first appeared on the World Wide Web (WWW) in April 1994. Visit our homepage at this address:

```
http://www.control.lth.se
```

Our web site contains information about personnel, publications, seminars, education etc. It also contains fairly complete lecture notes for many courses, and in some cases software tools such as Matlab toolboxes developed at the department.

Electronic Mail

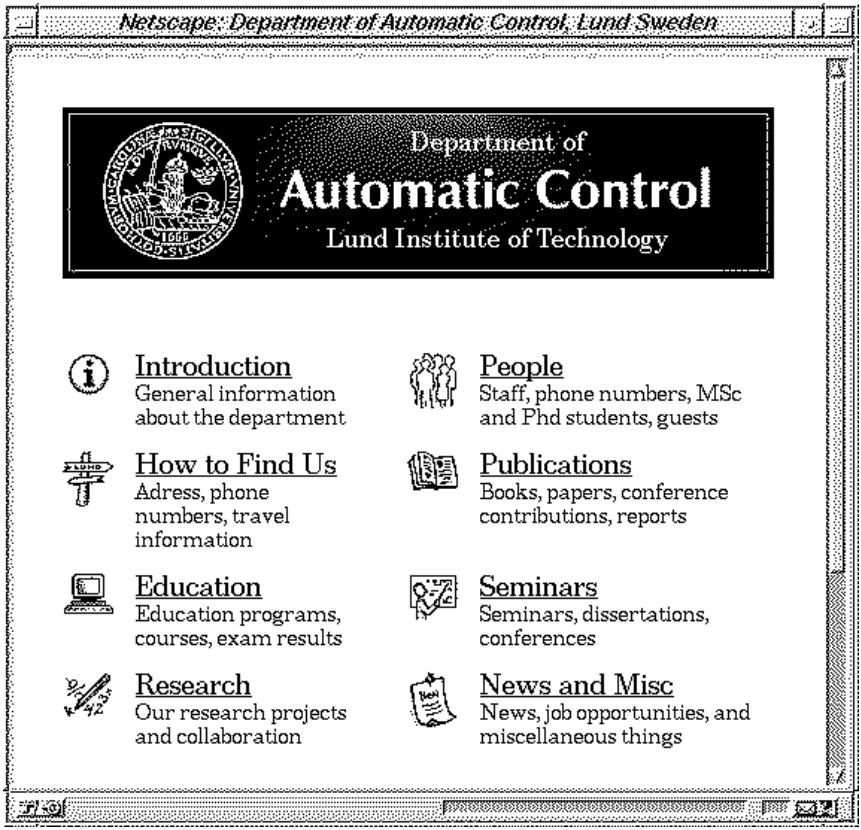
All personnel can be contacted by electronic mail. A personal email address consists of the full name and the department address, written in the form `FirstName.LastName@control.lth.se`. Double names are separated by underline, hyphens are treated as ordinary characters, and accents are ignored. Examples:

```
karl_johan.astrom@control.lth.se
bjorn.wittenmark@control.lth.se
karl-erik.arzen@control.lth.se
```

Our web page `http://www.control.lth.se/telemail.html` contains a complete list of email addresses. The department also has a generic email address:

```
control@control.lth.se
```

Letters to this address are continuously read by the postmaster and forwarded to the appropriate receiver.



Anonymous FTP

Via FTP you have access to various documents. The URL is:

```
ftp://ftp.control.lth.se/pub
```

Under the subdirectory `cace` you find documents regarding Computer Aided Control Engineering (CACE) and the program OmSim. There are versions of OmSim for Sun-4 workstations and HP workstations under the X Window System or PCs running under the operating system

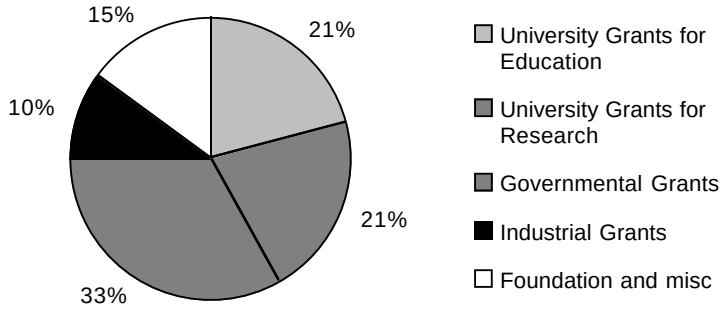
Linux. OmSim is implemented in C++ and uses only public domain software.

Under `books` you find material regarding the books *Adaptive Control* and *Computer-Controlled Systems*, both written by K. J. Åström and B. Wittenmark. Some of this material is used in the engineering courses.

During 1997 the subdirectory for Adaptive Control has been accessed from 287 different sites, Computer Control Systems from 372 sites, and OmSim from 350 sites.

3. Economy and Facilities

The turnover for 1997 was 23 MSEK, a slight increase compared to last year. The income comes from the University and from external grants; the distribution is shown below.



There has been a substantial reduction in the proportions coming from the university; 53% last year and 42% this year.

Funding

Lund University provides partial support for graduate students. The majority of our research is, however, externally funded from governmental agencies and industry. During 1997 we had the following contracts:

- TFR – Block grant
- NUTEK – Modelling and Simulation of Complex Systems
- NUTEK – Lund Research Programme in Autonomous Robotics
- NUTEK – Motion Control
- NUTEK – Autonomous Control
- NUTEK – Heterogeneous Systems

- NUTEK – Real-Time Systems
- NUTEK – Safety-Critical Systems
- NUTEK – Grafcet
- Governmental funding for research collaboration with Caltech
- MISTRA – Dynamic Modeling of an Ecocyclic Pulp Bleaching Plant
- ITM – Fuzzy Control
- ELFORSK – Modeling of Electric Power and Distribution Networks and Components
- Sydkraft – Modeling and Control of Energy Processes
- Pharmacia & Upjohn – Multivariable Control of Genetically engineered *E. coli*.
- EU HCM NACO – Nonlinear and Adaptive Control
- EU HCM EURACO – Robust and Adaptive Control
- EU ESPRIT FAMIMO – Fuzzy Algorithms for MIMO Control Systems

The Block grant from TFR is long range and some of the NUTEK projects are also long range. Several projects do, however, have a duration of only two years. To match these with the duration of a PhD, which is much longer, we have an internal research planning that is much more long range and we are careful to bid on projects that fit our long range research plan. This has proven an effective way to match short-term funding to long-term planning.

Facilities

The main facilites are laboratories and computer systems. Our main computing resource is a network of Unix workstations. All members of the department have workstations on their desks that are connected to this network. A continuing renewal of these workstations has taken place, so that about a third of the staff has SparcStation Ultras.

The teaching laboratories are based on desktop processes and personal computers. These laboratories are used in all our courses. The introductory courses give a heavy load on the teaching laboratories because of the large number of students. Our students spend on the average about 15 hours in the lab. With eight hundred students this means that the total load of the teaching laboratory is 12,000 student hours. The main teaching laboratory has been upgraded with modern powerful machines allowing a multiplicity of twelve groups of usually two students each. Apart from this we have a number of other lab machines that can be used for self-scheduled course projects, master thesis projects etc.

The lab processes that are used most frequently are tank systems, servos, and ball and beam systems. These have all been developed at the department. The development of an inverted pendulum with rotational pivot point (Tokyo Inst. of Technology configuration) has reached a stadium where multiple units are being built. We have integrated the flexible servos from Educational Control Products in our course on Computer Control Systems. The robotics laboratory was equipped with pneumatic gripper equipment, an (inverted) pendulum for benchmark problems and a dedicated TCP/IP connection to improve teleoperation and sensor data communication between laboratory units.

Windows NT is used as a soft real-time system so that the powerful user interface programs available for this system may be combined with control software, at least for moderate demands on the sampling frequency. Within NT's well-known limitations this has worked well.

An interesting new development is the use of the Multimedia Timer of Windows NT to handle a few special control loops with more stringent timing requirements. Sampling intervals down to 1 ms with low jitter are possible with this method.

4. Education

Engineering Program

The engineering education follows the central European systems with a 4.5 year program leading up to the degree “civilingenjör” (civ.ing.), which corrresponds to an MSc in the US and British systems.

Automatic control courses are taught as part of the engineering curricula in Engineering Physics (F), Electrical Engineering (E), Computer Engineering (D), Mechanical Engineering (M), and Chemical Engineering (K). The courses given at the department are listed in Table 1.

During 1997, 596 students passed our courses and 20 students made master-thesis projects. The number of registered students corresponded to 110 full-year equivalents during the year and the average passing rate was 74%.

Topics for the master theses were in the following areas: Nonlinear systems (1), Adaptive control and Autotuning (2), Modeling and simulation (5), Identification (2), Signal processing (1), Control design (2), Robustness (1), Real-time systems (1), Process control (2), Marine control problems (2), and Graphical User Interface (1). A list of the master theses is given in Chapter 13.

The first students were admitted to our 1.5 year Master’s Program this fall. They follow our elective courses and make a master thesis. A new course, Project in Control, was introduced for the Master’s students by Jan Sternby. This course will be offered to the students from the Engineering Physics program in spring 1999.

Interactive Learning Tools for Control

Courses in automatic control have to provide students with both a strong theoretical base and an engineering ability. The theoretical

Table 1. Courses in the engineering program given at the department. The figures show the number of students that passed our courses.

Reglerteknik AK–FED *FRT010* (Automatic Control, basic course)	287
Reglerteknik AK–M *FRT060* (Automatic Control, basic course)	128
Processreglering (K) *FRT080* (Automatic Process Control)	46
Digital Reglering (FED) *FRT020* (Computer-Controlled Systems)	41
Realtidsystem (FED) *FRT031* (Real-Time Systems)	46
Systemidentifiering (FED) *FRT040* (System Identification)	15
Adaptiv reglering (FED) *FRT050* (Adaptive Control)	20
Olinjär reglering och Servosystem (M) *FRT075* (Nonlinear Control and Servo Systems)	13
Examensarbete 15 poäng *FRT815* (Master-thesis project, 3 months)	1
Examensarbete 20 poäng *FRT820* (Master-thesis project, 4 months)	19

issues, typically related to mathematical techniques, can be well taught in the ordinary class room style. Engineering ability, on the other hand, requires an insight into dynamics and feedback which can sometimes be hard to convey.

In an effort to facilitate the learning and understanding of some key concepts in automatic control, we have developed a collection of interactive computer tools, ICTools. The tools, based on intuitive and highly interactive graphical user interfaces, have been found to be a powerful complement to textbooks and laboratories. The tools allow the students to explore different views of a system, manipulate the system directly using the mouse, and immediately see the consequences on the system behaviour, see Figure 4.1. The tools are particularly

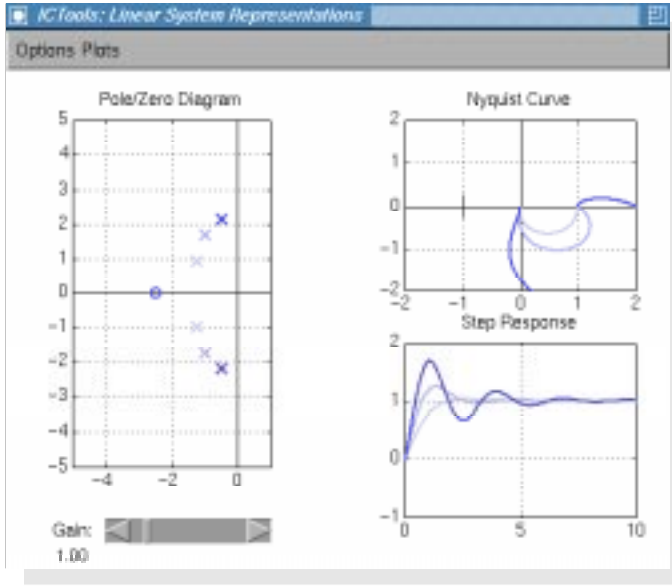


Figure 4.1 Interactive tool that illustrates representations of a linear system.

useful for the purpose of developing skills and insight, but can also be used for conventional tasks such as analysis and design. ICTools run under Matlab-5, which is available to all students through a site license. During the year, the tools and the associated study material have been successfully integrated in the basic control course.

The tools were tested in a large introductory course in automatic control with 357 students. An evaluation based on a sample of 20% of the students, showed that as many as 88% of the students found the computer-based self-study exercises to be good complements to the conventional teaching. The following is a sample of the comments from the students: *"Ok, now I understand more, fun," "... you made a great program!,", "The exercises were in general made available too late," "Fun, more of this."*.

More information is available at

`http://www.control.lth.se/~ictools`

The collection of Matlab modules for the course "Computer-Controlled Systems" is upgraded. Theoretical parts are introduced via simulations and a graphical user interface.

Both tool sets were featured in an article in the leading Swedish engineering magazine *Ny Teknik* 1997:48.

Revision of the Control Laboratory

A substantial effort has been made to revise the laboratory experiments used in our introductory courses. Using our new PCs running Windows NT new man machine interfaces have been developed also for the servo processes, see Figure 4.2 The commercial software InTouch is used.

The new interface has had a significant impact on teaching. It is now much easier for the students to focus on the essentials and they learn much faster. The experiments have also been revised and new manuals

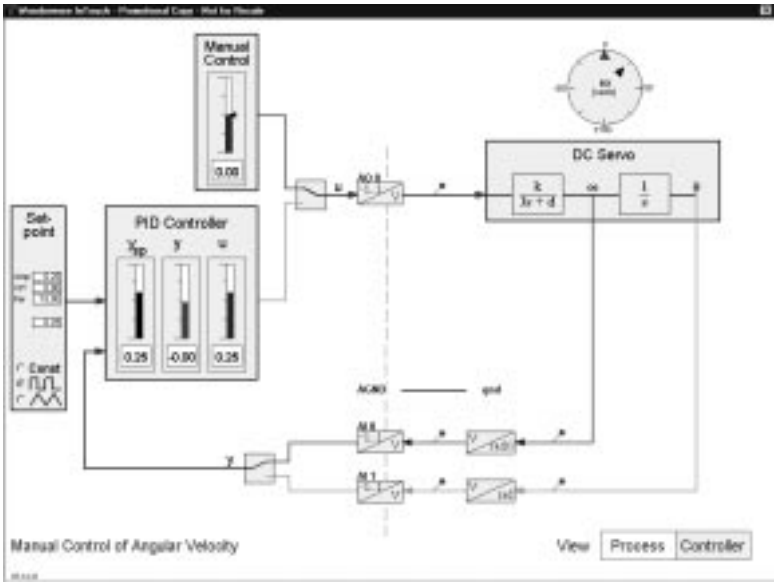
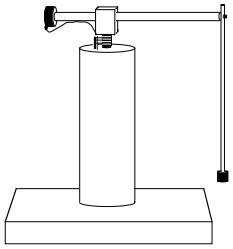


Figure 4.2 Man-machine interface for the servo control process.

have been written. The work was carried out by Tomas Schöntal and Tore Hägglund.



A new inverted pendulum with a rotational pivot point based on the design made by Prof Furuta at Tokyo Institute of Technology has been developed, see the figure. A first prototype was built and tested. Based on that a second prototype based on commercial components has been completed. It has now reached a development stage where multiple units are being built. The system is very well suited for a wide range of experiments in linear and nonlinear control.

The BEST Course

BEST (Board of European Students of Technology) is one of the major European student organizations. There are local BEST groups at 45 schools all over Europe. The major BEST activity is to arrange summer courses. In August 1997 the department in cooperation with BEST Lund organized the course *Dynamics and Control*. Twenty students from 15 European countries visited LTH during two weeks.

Dynamical systems were introduced from the state-space and the input-output viewpoints. Linear theory was presented in depth, nonlinear issues were discussed in less detail. The following topics were covered: linearization, stable, central, and unstable manifolds, poles and zeros controllability, and observability. Simple methods for control design were introduced. Bicycles were used as illustrations throughout the course. Relations between process and control design were discussed. Issues discussed included: What makes a bicycle un-ridable? Why is a bicycle with rear-wheel steering more difficult to control than one with front-wheel steering? What are the effects of centrifugal forces? How does the design of the front part influence ride-ability? Lectures and exercises were complemented by computer labs with Matlab and

Dymola and experiments with real bicycles, specially built for the BEST course.

Doctorate Program

One PhD thesis by Karl Henrik Johansson was completed during the year. This brings the total number of PhDs graduating from our department to 48. Three Lic Tech theses by Lennart Andersson, Johan Eker, and Charlotta Johnsson were defended. Abstracts of the theses are given in Chapter 8.

We have admitted four new PhD students during the year: Anna Delfin, Sven Hedlund, Mikael Petersson, and Lars Pedersen.

The following PhD courses were given:

- Hybrid Control (B. Bernhardsson) 2 points
- Control Paradigms (K. J. Åström) 2 points
- Real-Time and Fault-Tolerant Systems (K.-E. Årzèn) 4 points
- Autonomous Control (T. Hägglund) 4 points
- Linear Systems 1 (P. Hagander) 5 points
- Linear Systems 2 (P. Hagander) 5 points

Information

We have updated our information sheets about the engineering courses and the doctorate program, and they were received very well.

Many students have access to Internet via Lund University. Therefore we have made a great effort to present the education on web pages. Each course in the engineering program has its own homepage, where the students can find course plans, documentation, manuals, old exams, etc. See the URL:

```
http://www.control.lth.se/education/
```

5. Research

The goal of the department is to provide students with a solid theoretical foundation combined with a good engineering ability. This is reflected in the research program which, broadly speaking, is divided into theory and applications.

The major research areas are:

- Tuning, adaptation, and robust control
- Computer aided control engineering
- Applications

In the following presentation the research is broken down with a granularity of a PhD thesis. There are of course strong relations between the different projects.

Tuning, Adaptation, and Robust Control

This section covers research projects that are related to adaptive and robust control.

Friction, Modeling, and Compensation

Researchers: Karl Johan Åström and Magnus Gäfvert

This work, which is carried out in collaboration with LAG in Grenoble, has resulted in the LuGre model that captures many dynamic aspects of friction. A comprehensive survey paper that summarizes the results obtained so far was completed and accepted for publication. A detailed comparison of the LuGre model and the Bliman-Sorine model has been made. This has revealed interesting properties of both models and suggested improvements to the models. A new set of experiments have been planned at the Department of Mechatronics at KTH, where a unique experimental equipment is available. Experiments with friction

compensation of an inverted pendulum have been performed. This has demonstrated that the inverted pendulum is an excellent testbench. The experiments have clearly shown the advantages in using the dynamics friction models for compensation. There is a growing interest in friction modeling in a variety of fields such as geophysics, surface physics and chemistry. The models developed in the different fields are quite different and it is an interesting task to compare the models obtained in the different domains.

Control of Uncertain Systems

Researchers: Bo Bernhardsson, Ulf Jönsson, Michael Lantz, and Anders Rantzer

Recent developments in control theory are characterized by rapid improvements of computational tools for design, analysis, and simulation. This process is closely linked to theoretical progress in optimization theory and complex analysis. The aim of this project is to pursue this combined development of theoretical and computational tools, in directions motivated by industrial problems.

The main computational tool is non-smooth, convex optimization based on linear matrix inequalities. The theoretical challenge is to formulate practically important design and analysis problems that can be recast into this form. The historical development of control theory encourages this approach, since the literature contains numerous examples of challenging problems for which no computational tool was available at the time of their statement, but which now can be successfully addressed with new methods.

Many of the problems that can be solved in this way are in one way or another related to search for Lyapunov functions. This category includes well known analysis techniques based on structured singular values or quadratic stability and also synthesis methods based on optimal control with an LQG or H_∞ criterion. Our most recent research advancements show that many classical results related to the existence of globally quadratic Lyapunov functions, can be strongly improved in either of two ways. One is to introduce more freedom in the search by increasing the dimension of the state space. This has proved to be

effective in analysis of friction and hysteresis. The other way is to split the state space into smaller regions and to allow piecewise quadratic Lyapunov functions rather than globally quadratic. This seems to have a strong potential for systems with gain-scheduled or hybrid controllers.

In the case of parametric uncertainty in linear systems, the above methods reduce to computation of structured singular values. We are currently developing software tools to support the formulation of such problems. As an application example, we use a 16 generator model of the Scandinavian power network.

Another research topic in this area, motivated by a variety of engineering applications, is to find the smallest *real* perturbation of a matrix that changes its rank. We have now generalized our previous work on the real stability radius to the following, more general, problem. Given $M \in C^{p\times m}$, compute

$$\tau_k(M) := [\min\{\|\Delta\| : \Delta \in R^{m\times p} \text{ and } \operatorname{rank}(I_m - \Delta M) = m - k\}]^{-1}.$$

The following formula relates the real perturbation values, τ_k, to ordinary singular values.

$$\tau_k(M) = \inf_{\gamma\in(0,1]} \sigma_{2k}\left(\begin{bmatrix} \operatorname{Re} M & -\gamma \operatorname{Im} M \\ \gamma^{-1}\operatorname{Im} M & \operatorname{Re} M \end{bmatrix}\right),$$

where $\sigma_1 \geq \sigma_2 \geq \ldots$ denote the standard singular values of a matrix. In our 1997 paper in *Linear Alg. and Its Appl.* we also study the continuity properties of the map $M \to \tau_k(M)$, and we describe the connection to the so called pseudospectrum.

Modeling with Quantified Accuracy

Researchers: Anders Rantzer, Lennart Andersson, Sven Erik Mattsson, and Martin Öhman

This project has a two-fold background: experiences of object oriented modeling techniques from the Omola project and recent developments in robustness analysis. To deal with uncertainties we need concepts to describe them and tools for working with them. If a model is

developed from measured data using system identification methods we can get various statistical measures describing uncertainties. When models are developed from first principles, approximations are sources of uncertainty.

Mathematical tools for quantification of accuracy have been developed in the context of robust control. For example, the notions structured uncertainty and integral quadratic constraints, have been introduced to quantify the effects of neglected dynamics and parameter deviations.

Lennart Andersson's licentiate thesis "Comparison and Simplification of Uncertain Models" of February 1997 introduced new methods and error bounds for reduction of uncertain models. Currently, he is pursuing these methods further in the context of power networks. To analyse a regional network, it is necessary to simplify the models of network components far away from the region. The goal of the study is to get more systematic methods for such simplifications.

Another direction is taken by Martin Öhman. He is investigating model simplification in the neighborhood of nonlinear system trajectories. The trajectories can, for example, be the trajectories of an identification experiment, or the trajectories of some desired state transitions. Öhman's initial studies have been based on a boiler model for a power plant.

Multivariable Control

Researchers: Karl Henrik Johansson, Anders Rantzer, and Karl Johan Åström

Controlling a plant in process industry is a very large and complex problem. By tradition, it is solved by splitting up the problem into design of many simple control loops. This has proved to be a rather successful approach, however, at the cost of possible limitations on the overall plant performance. It is well-known that the simple control loops can influence each other and cause degradation in the achievable control quality for each process output. It is therefore important to select the control loops carefully. In this project systematic ways of chosing control structures are investigated.

Limitations imposed by a diagonal control structure have been quantified and the implications on sequential control design have been shown.

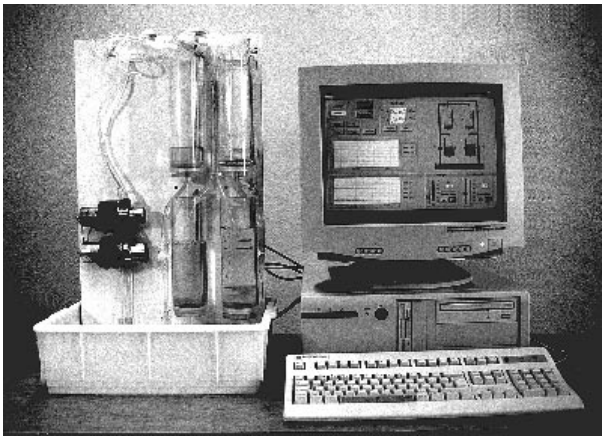


Figure 5.1 Quadruple-tank process

The quadruple-tank process in Figure 5.1 has been developed to illustrate performance limitations in multivariable control systems. The linearized model of the quadruple-tank process has a multivariable zero, which can be located in either the left or the right half-plane by simply changing a valve.

Hybrid Systems

Researchers: Karl Johan Åström, Bo Bernhardsson, Karl Henrik Johansson, and Jörgen Malmborg

Hybrid systems is an active research area on the border between Computer Science and Automatic Control. A typical hybrid system consists of a physical process under control and supervision of a discrete computer. Physical systems may show behavior that is convenient to model as discrete events. Examples are mechanical systems with backlash, dead zones, and static friction, or electrical systems with switches. A valve in a process model may become stuck because of high friction. Switching between the two states “stuck” and “moving” are discrete events. Whether a physical phenomenon is modeled as a continuous evolution or a discrete event, depends on the desired level of detail in the model, and its relative time scale, compared to other

interesting phenomena in the system. It may also be advantageous to use control strategies with switching for continuous processes.

In this project it is attempted to use switching strategies to improve the performance of simple controllers and facilitate controller design. We have implemented a hybrid control system consisting of a time optimal controller and a PID controller together with a switching algorithm. The system shows very good performance when controlling the levels of a double tank system. We have also investigated how simulation tools can be improved to give better results for hybrid systems. As prototype systems, we have studied simple discontinuous differential equations. "Sliding modes," which were introduced by the Russian mathematician Filippov, have been analyzed. For example, we have derived conditions for the approximation of a solution by a sliding mode for some systems. This simplifies the simulation of the system.

The Department is a member of the ESPRIT Working Group "Tools for the Analysis of Hybrid Systems."

Automatic Tuning of PID Controllers

Researchers: Karl Johan Åström, Tore Hägglund, Karl Henrik Johansson, and Hélène Panagopoulos

This project has been in progress for over ten years, and resulted in industrial products as well as several PhD theses. A monograph on PID control that is based on experiences obtained in the project has also been published.

During the last year, the project has focused on improvements of PID controller design. Numerically robust design procedures for PI and PID controllers are currently under development. An efficient numerical method for designing PI controllers based on non-convex optimization has been developed. The design is based on optimization of load disturbance rejection with constraints on sensitivity and weighting of setpoint response.

Automatic tuning of multivariable controllers has also been studied. In collaboration with Prof. Greyham Bryant and his group at the Centre for Process Systems Engineering at Imperial College in London, a

method has been derived for tuning a single loop in a multivariable system.

Autonomous Control

Researchers: Karl Johan Åström, Tore Hägglund, and Anders Wallén

This project, which is supported by NUTEK, builds on earlier projects on tuning and adaptation of PID controllers and expert control. It has been inspired by industrial experiences on tuning of PID controllers. The aim is to demonstrate a concept of a single-loop controller with as much autonomy as possible. It is supposed to help the operator start up, tune and monitor the control loop. The start-up procedure should contain tools that can provide *loop assessment* in order to detect non-linearities, faulty equipment, poorly tuned processes etc. Loop monitoring includes actuator *diagnosis* and *performance assessment*. The latter function attempts to determine if the loop performs according to its specifications and also to compare with historical data and theoretical limits.

The autonomous controller contains a wide range of algorithms and methods of quite different nature. It includes traditional real-time computations, sequential methods for loop assessment and tuning, and knowledge-based methods. We have a G2 prototype implementation using extended Grafcet for structuring the control algorithms. A major concern has been to design supervisory logic for the various algorithms.

The work on development of new supervisory functions has continued. The Knocker, a procedure to compensate for static friction in control valves, has been patented and implemented in industrial DCS systems. A new procedure that detects sluggish control loops has also been developed and tested on industrial plants.

Integrated Control and Diagnosis

Researchers: Karl-Erik Årzén and Mikael Petersson

The goal of this project is development of methods for integrated design and diagnosis functions, development of model-based diagnosis functions, and implementational issues of on-line diagnosis systems. During the year Mikael Petersson has started as a PhD student within this area.

System Identification

Researchers: Rolf Johansson (in cooperation with Prof. M. Verhaegen, TU Delft)

An identification algorithm that effectively fits continuous-time transfer functions and finite-bandwidth noise models to data has been published. Analysis of this class of algorithms proves convergence properties similar to that of maximum-likelihood identification of discretetime ARMAX models. A substantial improvement of the identification accuracy of continuous-time zeros appears to be an important and attractive property of the new algorithm. One research direction that is currently pursued is system identification methodology suitable for multi-input multi-output systems for which matrix fraction descriptions are not unique. A promising approach to system identification appears to be the continued-fraction approximation and we have published a number of new matrix fraction descriptions and theoretical results that resolve such problems of uniqueness. However, several theoretical problems remain to be solved with regard to algorithm efficiency, statistical properties and validation aspects.

Computer Aided Control Engineering

Computer Aided Control Engineering, CACE, has been a major area of research at the department for a long time. It has the dual purpose of providing tools for making control engineering much more cost effective and it also provides a glue between many different research projects.

During 1997 the focus has been on the design and development of Modelica as well as tools for modeling and simulation of hybrid systems. Major applications have been power generation and power distribution.

Modeling and Simulation of Complex Systems

Researchers: Jonas Eborn, Sven Erik Mattsson, Bernt Nilsson, Tomas Schönthal, and James Sørlie

This project is a part of NUTEK's research program on Complex Systems. The main aim of this project is to develop methods and computer tools which support development and use of mathematical

models. Structured model libraries and more application specific tools are developed in other related projects as described below in cooperation with external partners.

The basic idea is to support reuse, so that a model component can be used as a part in different applications to solve a variety of problems. Good model libraries should allow a user to make the desired model simply by combining components. Computer tools shall automate the analysis and manipulation, which the user have to do manually today to get the problem on a form that is efficient for numerical solution.

Since more than 10 years we have had a vision of a unified modeling language for physical systems modeling. There is now a real chance that this vision will become true in the very near future. We participate in an international project to design such a language. The project started in September 1996. The main objective was to make it easy to exchange models and model libraries and to allow users to benefit from the advances in object-oriented modeling methodology. The language is called Modelica[1]. Version 1 was released in September 1997. The language definition and other information on the Modelica effort are available on WWW at `http://www.Eurosim.tuwi2en.ac.at/Modelica/`.

The Modelica effort started in the continuous time domain since there is a common mathematical framework in the form of differential-algebraic equation (DAE) systems. Modelica version 1 is based on DAE systems with some discrete event features to handle discontinuities and sampled systems. Our research focuses now on modeling and simulation of more general hybrid systems. This is a wide open area, where there are many fundamental questions to answer such as which are the natural representations and how are these models simulated in an efficient way.

Development of model libraries in Modelica is important and it is an aim of the applied projects described below to contribute to this.

[1]Modelica is a trade mark of the Modelica Design Group

Modeling and Control of Energy Processes

Researchers: Karl Johan Åström, Rodney Bell, Jonas Eborn, Sven Erik Mattsson, Bernt Nilsson, James Sørlie, and Martin Öhman

The main aim of the project is to develop methods and computer tools that support development, analysis and use of mathematical models in energy process applications. This project is a cooperation with Sydkraft Konsult AB.

In an earlier joint project with Sydkraft we have developed a set of model libraries called K2 with basic models for thermal power generation. The models have been developed in Omola and are used for research as well as in Master's thesis projects. The libraries are general enough to cover several process applications. During 1997 the libraries have been used in two Master's projects concerning heat exchangers using steam condensation and HVAC systems.

Professor Åström has for a long time worked on developing simple non-linear models of drum boilers. The work in collaboration with Dr Rodney Bell of Macquarie University in Australia has resulted in a suite of models with complexity ranging from first to fifth order. The latest results capture the crucial shrink-and-swell phenomenon of the liquid level in the drum almost perfectly.

Model libraries and models need to be validated against measured data to be of industrial value. For linear model structures there exists theory and many tools for doing this. For non-linear physical models however, there is no systematic approach for model validation that we know of. A possible approach that has been tried in this project is parameter estimation. Optimal estimates of physical parameters can be compared with a-priori known values and provide a measure on the quality of the model. To do this an interface between the simulation and the optimization tool is essential. We have developed such an interface and used it in a case-study to obtain optimal parameter values for the Bell-Åström drum boiler model. The almost perfect fit seen in Figure 5.2 verifies that the model structure captures all the observed dynamics.

Large complex mathematical models are today mainly used for simulation and optimization. It is common engineering practice to work with

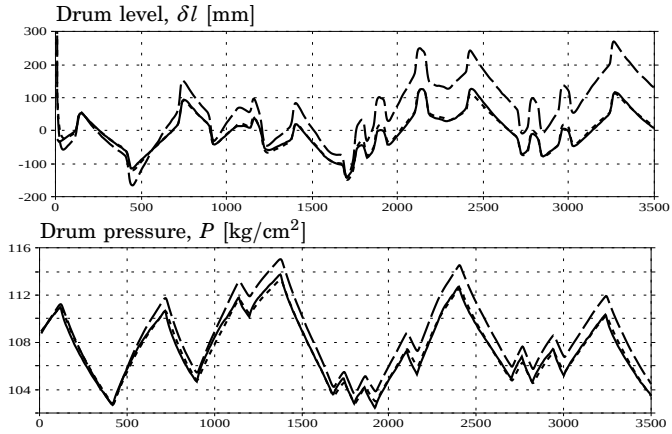


Figure 5.2 Measurements from Öresundsverket (—) compared to simulation with nominal parameters (– –) and optimized parameters (- - -).

as simple models as possible. They are easier to analyze and evaluate. For design of controllers, simple time-invariant linear models are used in most cases. There is a well-established theory as well as commercial computer tools for design of controllers with given specifications. To verify that the controller works well also in reality, simulation with more complex models is used. It would be very nice if there were methods and tools for extracting simple models for specific purposes from a large complex model. For linear models there are well-established approaches to model simplification or model reduction. This project puts the user in focus. The aim is to provide tools for exploration of the model to investigate dependences between variables and impacts of terms in equations to see if terms or dynamics can be neglected or if non-linear relations can be replaced by linear ones.

Modeling of Electricity Distribution Networks and Components

Researchers: Erik Möllerstedt, Sven Erik Mattsson, and Bo Bernhardsson

The project is financed by Elforsk AB under NUTEK's Elektra program. The increased use of switched power supplies and power electronics creates disturbances in the wave form of the supplied electricity, resulting in increased losses, overheating, and failure of sensitive

equipment. However, power electronics also bring up new possibilities to control, filter, and protect power networks in a more sophisticated way. To be able to utilize this improved control authority, models and methods to analyze and simulate the networks are needed.

Typical distribution networks such as a shopping center, an office building or a local district with fifty houses, two factories and two transformer stations have many components. To beat complexity it is useful to work with aggregated models. However, it is not straightforward to develop aggregated descriptions, because there are highly non-linear components such as fluorescent tubes and switched power supplies.

We have developed a new method for modeling of harmonic distortion. It is a variant of harmonic balancing, where the voltage and currents in stationarity are described by truncated Fourier series. The method exploits that the loads are connected in parallel, which means that the voltage is approximately the same for all loads and that there are norms for allowed voltage distortion. Thus, it is reasonable to assume a linear relationship, $I = I_0 + Y(V - V_0)$, between the Fourier coefficient vectors of the current, I, and voltage V, where I_0 is the nominal current spectrum when the voltage is nominal V_0. The matrix Y can be interpreted as an admittance matrix that describes how the current spectrum is affected by changes in the voltage spectrum. Each column in Y describes the change in the current spectrum when a small component of a certain harmonic is added to the nominal voltage. If the component is linear then Y is diagonal. The parameters, I_0 and Y for a component can be obtained from simulations of a complex component model or from real measurements, which means that detailed physical modeling is avoided. It is easy to aggregate linear descriptions. Network solving is a non-iterative procedure based on linear algebra. Thus giving efficient calculations without convergence problems.

Dynamic Modeling of an Ecocyclic Pulp Bleaching Plant

Researchers: Anna Delfin, Sven Erik Mattsson, and Björn Wittenmark

This is a subproject within the project "The potential of pulp and paper production as an energy producing and truly ecocyclic process," which is funded mainly by MISTRA, and to a smaller extent by the Swedish

pulp and paper industry. The work is done in cooperation between a large number of departments in Sweden, and the project is coordinated by the Swedish Pulp and Paper Research Institute (STFI), Stockholm. For more information see: `http://www.stfi.se/mistra/kamprog.htm`

The goal of our subproject is to develop a dynamic model library that supports modeling of ecocyclic pulp bleaching plants. There is a need for better understanding of the process dynamics and of the possibilities to control bleaching processes. It is of a particular interest to study the enrichment of metal ions due to the recirculations, since these ions have a very negative impact on the bleaching process. It is necessary to have artificial kidneys that remove the metal ions that come with the wood and the water.

This project may be thought of as collecting and formalizing modeling knowledge in order to make it easy to use. In the first phase of the project the models are based on material from the literature and information and knowledge from our industrial partner Södra Cell AB, Mörrum, Sweden. The idea is to develop a model architecture, which makes it easy to put together models for different plant configurations and to modify and update model components when new results become available from other subprojects that deal with basic modeling of components or physical or chemical phenomena. The model is developed in the object-oriented modeling language Modelica.

Applications

Apart from the applications of computer aided control there are several other application projects going on at the department, in robotics, real time control, fuzzy control, motion control, as well as control of processes in steel industry, biotechnology, and biomedicin.

Robotics

Researchers: Rolf Johansson, Klas Nilsson, and Anders Robertsson

The laboratory for robotics and real-time systems is centered around an ABB Irb-6 robot and an ABB Irb-2000 robot. Hardware interfaces

have been developed to create an open system suitable for control experiments. The computer hardware is VME-based with both micro processors and signal processors integrated into an embedded system for hard real-time control. The system is connected to a network with Sun workstations, which are used for program development and control design. A purpose of the current project is to show how to organize open robot control systems and to verify these ideas by means of experiments. One goal is to permit efficient specification and generation of fast robot motions along a geometric path, which requires coordinated adjustment of the individual joint motions. Another aspect of robot motion control is how to to integrate simultaneous control of force and position according to ideas of impedance control in which stability is an important theoretical issue. A major topic in this project is to integrate aspects of control, sensor fusion and application demands.

Another project is on the structure and programming of control systems for industrial robots. The problem addressed is how the software architecture and the real-time structure of a robot control system should be designed to allow easy and flexible incorporation of additional sensors and new control algorithms. A software layer between a supervisory sequence control layer and the basic control level has been proposed. Case studies and prototype experiments show promising results and further implementation is going on. Klas Nilsson spent 4.5 months of research work assignments at ABB Robotics. A NUTEK-sponsored research program Lund Research Programme in Autonomous Robotics with cooperation partners from Dept Production and Materials Engineering and Dept Industrial Electrical Engineering and Automation and industrial partners was continued during the year.

Real-Time Control

Researchers: Leif Andersson, Karl-Erik Årzén, Anders Blomdell, and Johan Eker

An ongoing research project named “Application specific real-time systems” studies real-time programming and real-time kernels/primitives. This is done along three lines of development.

1. Improvements of traditional (industrially accepted) approaches.

2. Use of formal methods to ensure correctness.
3. Application aspects for embedded control systems that are open and layered.

The project is supported by NUTEK's Embedded Systems Program.

For the traditional approach, a real-time kernel developed within the department has been improved and extended. It allows us to easily introduce new real-time solutions. The kernel supports M68k processors, Windows NT and Sun Solaris. During this year the kernel has been ported also to PowerPC processors and to the M68340 processor. The latter was done to allow experiments with control loop delays on CAN buses. The kernel also supports fast (1 milli-second) sampling under Windows NT through the use of the NT multimedia interrupts.

A toolbox for rapid prototyping of real-time applications has been developed. The language PAL (Pålsjö Algorithm Language) is used for describing real-time processes, which are compiled and downloaded to a VME-target computer. The run-time environment allows real-time configuration of the system. The PAL-compiler also supports the GRAFCET-1131 standard. During the year Johan Eker has completed his licentitate thesis "A Framework for Dynamically Configurable Embedded Controllers," where Pålsjö and PAL are described.

Industrial robot control systems are used as a typical demanding real-time application. We have a well proven experimental platform including two ABB robots controlled from our VME-based computers with Sun workstations being used as host computers. This means that the real-time research is well integrated with the robotics research. During 1997 Klas Nilsson, who formerly was responsible for the robotics laboratory has worked for the Department of Computer Science. The laboratory has been used as an interface between the research performed at the two departments. During the year several interesting experiments have been performed. In one example the robot holds an inverted pendulum, swings up the pendulum from downward to upward position, and balances it in the upward position. Experiments have also been performed with vision feedback on the ball and beam process.

An activity that has close relations to real-time control is the work we are doing on graphical Petri net and Grafcet based languages for sequential supervisory control applications. The platform for this work is G2, a commercial object-oriented environment for real-time applications. We have developed Grafchart, a toolbox that combines real-time expert system techniques with Grafcet. This is a commercial product that currently is being applied for supervisory control in a US oil refinery and for the automation of flexible machining cells in Spain. Grafchart is currently being extended in different object-oriented directions.

During the fall a proposal on "Integrated Control and Scheduling" was approved by ARTES, the Swedish real-time systems research network. The project, that is a cooperation between our department, the Department of Computer Science, Sigma Exallon Systems AB, and Software Engineering Institute at Carnegie Mellon University, will begin in the spring of 1998.

High-Level Grafcet for Supervisory Sequential Control

Researchers: Charlotta Johnsson and Karl-Erik Årzén

This research project is funded by NUTEK under the REGINA programme. Sequential Control is extremely important in industry both for continuous, discrete, and batch processes. It is needed both at the direct control level and for supervisory control applications.

During the last years Grafcet, or SFC (Sequential Function Charts), has emerged as an international standard for direct level sequential control, through the standards IEC 848 and IEC 1131-3. Grafcet, which is a graphical programming language, has been very well accepted in industry. However, today there is also an industrial need of a graphical programming language suited for sequential control at all control levels.

Grafcet has its roots in Petri Nets. In parallel to the development of Grafcet, High-Level Petri Nets have been developed from ordinary Petri Nets. High-Level Petri Nets combine the expression power of high-level programming languages with the formal specification language properties of Petri Nets while preserving the user-friendly graphical representation.

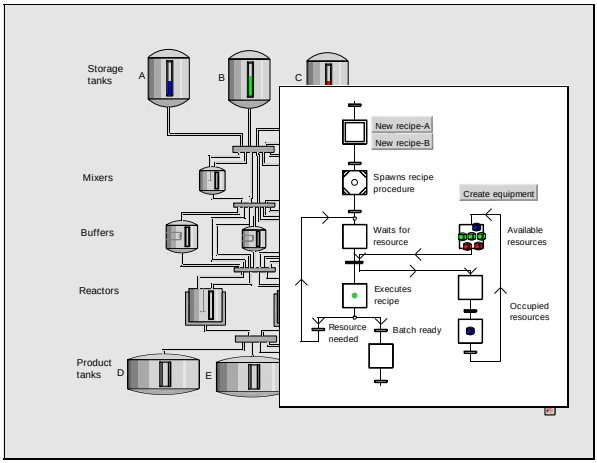


Figure 5.3 Batch process with recipe

The goal of this project is to develop Grafcet into High-Level Grafcet and thereby make it amenable also to supervisory control applications.

The work is based on Grafchart, a Grafcet toolbox developed at the department since 1991. The toolbox is implemented in G2, an object-oriented graphical programming environment. It has already been used in industry with great success. High-Level Grafchart is an extension to Grafchart that is currently under implementation. Grafchart is extended with object-oriented programming languages constructs and ideas from High-Level Petri Nets. The new features in High-Level Grafchart, compared with Grafcet, are procedure steps, process steps and exception transitions, parameterization, methods and message passing, object tokens, and multi-dimensional charts.

This project focuses especially on batch control applications. In this context it is investigated how High-Level Grafchart can be used for recipe representation according to the recent standard, ISA-S88.01, for batch control. By using the features of High-Level Grafchart in various ways, recipes can be given different structures with different advantages and disadvantages. Since High-Level Grafchart is based on

Grafcet, the recipes have a clear and intuitive syntax. The recipes can also be analyzed, with respect to deadlock situations, using the Petri net analysis methods. An on-line simulator of a multi-purpose, multi-path batch-cell has been developed and implemented in G2, see figure 5.3, and is used as a test platform.

The project has an industrial steering- and reference-committee consisting of members from Alfa-Laval Automation, ABB Industrial Systems, Astra, Kabi Pharmacia and van der Bergh Foods. In June 1997, Charlotta Johnsson presented her licentiate thesis "Recipe-Based Batch Control Using High-LevelGrafchart."

Design and Tuning of Fuzzy Controllers Based on Non-Linear Control Theory.

Researchers: Mikael Johansson, Karl-Erik Årzén, and Anders Rantzer

The aim of this project is to apply conventional control theory to develop new methods for design and tuning of fuzzy controllers. The project is funded by ITM (The Swedish Institute for Applied Mathematics), Volvo and ABB. The industrial sponsors provide two industrial applications on which the results will be tested. These are car climate control and control of electric arc steel furnaces.

The theoretical work in the project has been focused on stability and performance analysis of fuzzy control systems. With the basic observation that many fuzzy control systems have piecewise linear dynamics, analysis methods for such systems have been developed. The methods use piecewise quadratic Lyapunov functions that can be computed using convex optimization techniques. The method appears to have a strong potential for analysis of a wide class of nonlinear systems. The project ended September 31, 1997, and this line of research is now pursued within the FAMIMO project.

FAMIMO

Researchers: Sven Hedlund, Mikael Johansson, Karl-Erik Årzén, and Anders Rantzer

FAMIMO (Fuzzy Algorithms for MIMO Control Systems) is a three year Esprit reactive long term research (LTR) project that started

December 1, 1996. The project has four academic partners and one industrial partner, Siemens Automotive in Toulouse. The project is organized along two benchmark studies: control of a direct fuel injection engine and control of a wastewater fermentation process. Each partner will apply their favorite design method. The approach that is used in Lund is an heterogeneous, local controller approach, where fuzzy logic is used to implement interpolation. During 1997 a technical survey on fuzzy control has been written. The implementation of a Matlab toolbox for analysis and synthesis of piecewise linear systems has also been started.

Motion Control

Researchers: Karl Johan Åström, Mattias Grundelius, and Tore Hägglund

Motion control systems are common elements in manufacturing systems. They have a significant influence on quality and production capacity. Traditionally, motion control problems were solved with pure mechanical devices, but there are now many interesting alternatives that combine mechanical systems with different forms of motors and control systems. Such systems are typical cases where trade-off of control and process design is very important.

During this year, the focus in the project has been indexing of packages containing liquid. All packages in the machine follows the same acceleration profile, each package is moved (indexed) several times in the machine. Between the filling station and the sealing station the package is indexed 3 to 5 times. The aim is to find the acceleration profile that minimize the indexing time with a maximum allowed slosh.

In order to compute the optimal acceleration profile we need an accurate model of the slosh in the package. The modelling requiers that we can measure the slosh. We have tried different methods to measure the slosh in the package. This proved to be hard and has delayed the modelling part of the project. Preliminary optimization has been performed on a simple model. Evaluation on the experimental setup showed that the simple model was not sufficient to the describe the slosh in the package. The project is funded by NUTEK under the REGINA program. It is performed in close collaboration with Tetra Pak Research & Development AB in Lund.

Modeling and Control of Processes in the Steel Industry

Researchers: Lars Malcolm Pedersen and Björn Wittenmark

The research is focused on modeling and control of two main processes in the steel industry:

- a hot plate rolling mill
- a slab reheat furnace

The work is carried out in cooperation with the Danish Steel Works Ltd., which delivers data and information about the processes while the research work is carried out at the Department of Automatic Control.

The work with the control of the hot rolling mill has been concentrated on deriving a multivariable nonlinear control algorithm for the control of plate thickness. The design of the control algorithm is based on a multivariable nonlinear model obtained using data collected from the hot rolling mill at The Danish Steel Works Ltd. We are currently working on implementation of a simplified version of the control law.

So far the work on furnace control has covered control of the slab temperature. Here a model for the slab temperature has been derived, the control problem has been formulated and a nonlinear controller has been designed. The controllability and stability of the system has also been investigated. The slab temperature model is based on data the reheat furnace no. 2 at the Danish Steel Works Ltd. Future work includes modeling and controller design for the furnace temperature.

Timing Problems in Real-Time Systems

Researchers: Bo Bernhardsson, Johan Nilsson, and Björn Wittenmark

This is a subproject within the DICOSMOS project, (Distributed Control of Safety Critical Mechanical Systems). DICOSMOS is a cooperation between Department of Computer Engineering, CTH, Department of Mechanical Elements, KTH, and Department of Automatic Control, LTH.

The work in Lund has focused on analysis and design of control systems with communication delays. The results are presented in the PhD thesis by Johan Nilsson, “Real-Time Control Systems with Delays” (1998).

Methods for analysis of stability and performance properties have been developed. A new optimal control scheme has been suggested and analyzed. The new scheme uses so called "time-stamping" of control and measurement messages. The optimal controller has been shown to have the separation property. We have also shown how to use the frame-work of so called jump linear systems to analyze random network delays.

Network delays, or network transfer times, have different characteristics depending on the network hardware and software. To analyze control systems with network delays in the loop we have to model these. Three models of different complexity have been studied. The network models are:

- Constant delay
- Random delay, which is independent from transfer to transfer
- Random delay, with probability distributions governed by a Markov chain

To design a controller for a distributed digital control system it is important to know how to analyze such systems. In standard computer control theory it is assumed that the closed loop system is time-invariant. In a system with varying delays this is not true. In the work it is shown how to analyze linear controllers where the network delays are described by one of the three developed network models above.

The Linear Quadratic Gaussian (LQG) optimal controller has been developed for the network models. The derived controller uses knowledge of old time delays. These can be calculated using "time-stamping" of messages in the network. The solution to the LQG-problem was found by combining an LQ-controller with a Kalman filter. It was shown that a separation principle holds, design of state feedback and state estimator can be done independently.

The developed theory has been tested in small examples. Controllers from the literature have been compared with the developed synthesis method. It is found that the developed control algorithm increases stability and performance of the control system.

Control of Biotechnology Processes

Researchers: Mats Åkesson and Per Hagander in cooperation with Jan Peter Axelsson (Pharmacia & Upjohn) and Olle Holst (Department of Biotechnology, Lund University)

Many pharmaceuticals and chemical products are today produced using genetically modified microorganisms. In fermentation processes, living cells are grown to large numbers and then made to produce some desired substance, often a protein. Fed-batch fermentation, where additional substrate is fed to the culture during the fermentation, is often a preferred way of production. In order to achieve reproducible cultivations with high cell densities and high productivity, it is important to design good strategies for the substrate-dosage control.

A project on substrate-dosage control of fed-batch units with genetically modified *E. coli* is performed on a contract with Pharmacia & Upjohn, Bioprocess Development. Information of how to change the substrate feed rate is obtained from standard measurements by introducing controlled process perturbations. Only little process specific information is required, which makes this strategy well suited for new processes.

The tuning of the strategy is verified using models obtained from experiments performed in collaboration with the Department of Biotechnology, Lund University.

Modeling of Postural Control

Researchers: Rolf Johansson in cooperation with Dr Måns Magnusson (Department of Oto-Rhino-Laryngology, Lund University Hospital)

The project is directed towards assessment of normal and pathological human postural control. System identification and mathematical modeling of the dynamics in postural control are studied with special interest on adaptation, reflexive and anticipatory control. Reflexive and voluntary eye movements are studied in patients with lesions related to balance disorders. Experimental studies, with special reference to the level of alertness, are undertaken to enhance understanding, diagnosis and treatment of dizziness and vertigo. A major complication is that human postural control is characterized by multi-sensory feedback control (visual, vestibular, proprioceptive feedback) and this fact is reflected

both in experiment design and analysis. Special interest is directed to the importance of cervical and vestibular afference. To this purpose, stability properties are studied by means of induced perturbations specific to each sensory feedback loop by using system identification methodology. The work is supported by the Swedish Medical Research Council and the Faculty of Medicine, Lund University.

Cardiologic Analysis and Modeling

Researchers: Rolf Johansson in cooperation with Dr. Magnus Holm and Prof. S. Bertil Olsson, (Dept. Cardiology, Lund University Hospital)

This project is directed towards chronic atrial fibrillation (CAF), one of the most common cardiac arrhythmias in man and associated with increased morbidity and mortality. Previous studies in animals have shown that experimental atrial fibrillation is based on different types of intra-atrial electrical re-entry. By exploring the activation of the right atrial free wall during open-heart surgery in patients with CAF and an underlying heart disease, we confirmed the presence of re-entry mechanisms. In addition, areas with organised activation were identified. The nature of the organised activation suggested re-entry in an anatomical structure, like the right annular bundle surrounding the tricuspid valve. In patients without signs of organised activation, multiple activation waves continuously re-enter due to functional properties of the atrial myocardium. An interesting result was that we failed to demonstrate that anisotropy in conduction velocity be a general property of the epicardial right atrial free wall of the intact human heart in patients with stable sinus rhythm as well as in patients with CAF. In 1997 Magnus Holm defended his PhD thesis entitled “Chronic atrial fibrillation in man. Activation, organisation and characterisation.”

6. External Contacts

The roles of the universities in technology transfer has recently been emphasized in Swedish research policy as the “the third mission” (tredje uppgiften). This means that we now also have responsibility for transfer of research to industry.

At present we have a healthy mixture of fundamental and applied work. The purpose of the theory activity is to develop new ideas, concepts and theories that capture the essence of real control problems. We are of course delighted to find applications of the theory but the focus is always on methodology. In the applications projects the goal is to solve real control problems together with external partners. In these projects the problems are approached with an open mind without glancing at particular methods. One purpose is to learn about real problems, another is to learn about new problems that are suitable for theoretical research. The applications projects also provide very good background for our educational activities.

Technology transfer takes many forms. One is to take results from our research and present them so that they are easy to use. Probably the best way to do this is through personal exchange between industry and university. Students are a very effective vehicle for the transfer.

Realizing that the majority of the research is done outside Sweden another important role for universities in a small country is to take existing knowledge and organize it in such a way that the results can easily be digested by engineers in industry. There is naturally a strong symbiosis with teaching in this activity. A good mechanism is thus to introduce new research material into existing and new courses. A related form of technology transfer is to write books and monographs and to develop software. We have been active in technology transfer for a long time, good examples of this type of exchange where we

have transferred ideas are self-tuning control, automatic tuning and computer-aided control engineering. More details have been presented in previous activity reports.

Industrial Contacts

We have very good working relations with several companies and organizations. The interaction are at many different levels and intensities, from visits and discussions to joint projects. Master theses and education are also important ingredients. This year we have made substantial efforts to increase the industrial interaction. During the year we have had major projects with

ABB Corporate Research,
ABB Robotics
Alfa Laval Automation,
The Danish Steel Works Ltd.,
Danfoss AS,
Diana Control AB,
Dynasim AB,
Gensym Corp.,
Pharmacia & Upjohn,
Siemens Automotive,
Sydkraft,
Tetra Pak.

We have had smaller projects with

ABB Industrial Systems,
ABB Power Systems,
Astra Draco,
Astra Hässle,
Alfa Laval Thermal,
Cellavision,
Comsol,
Ericsson,
Elforsk,

Industrial Communications,
Modo Paper Husum,
Novotek,
Pulp and Paper Industries Engineering Co. (STFI),
SIK – Institutet för livsmedel och bioteknik AB,
Södra Cell, Mörrums Bruk,

and meetings and discussions with a few other companies.

European Collaboration

The department is participating in two networks in the EU Human Capital and Mobility Program. The network HCM NACO, *Nonlinear and Adaptive Control*, is a cooperation between seven different universities. The network HCM EURACO, *European Robust and Adaptive Control Network*, consists of 12 universities.

We are also a member of the ESPRIT project, FAMIMO, *Fuzzy Algorithms for MIMO Control Systems*. The project has four academic partners and one industrial partner, Siemens Automotive in Toulouse.

There has been a large exchange of visitors within the networks and Lund has been one of the most popular sites to visit.

7. Looking Back on Real-Time Systems

Introduction

There have been very strong couplings between control engineering and computer science from the very beginning of the fields. An illustration is that the Whirlwind computer, which led to development of core memories as well as the minicomputer, was developed at the Servomechanism Laboratory at MIT. Control engineering was initially focused on analog computing. Analog computers were used for analysis and implementation. Traditionally, a good control engineer had to master analog computing because it was a major aspect of his work. Today it is equally important that a control engineer masters digital computers and real-time systems. In this chapter we will review the activities in real-time computing at our department.

The Beginning

The activity on real-time control started from the conviction that it is absolutely essential for control engineers to have a good grasp of real-time control systems. Possibilities and restrictions in implementation will always have a profound influence on analysis and design of control systems. Too much is lost if there is not a strong interaction between control engineers and computer scientists. This was emphasized in the research program for the department written in 1969. At that time we were in the process of purchasing the first computer for the department. The requirements for the computer were based on experiences of development of early industrial

real-time operating systems. A prime requirement for our computer was real-time control. At that time the central computing center at the university was responsible for all computers, and an individual university department was not allowed to buy a computer on its own. Therefore, the term "real-time simulator" was used instead of "computer" during the purchasing process. Eventually this led to the purchase of a Digital Equipment PDP-15 in 1970. The main memory was expanded from the normal 8 kilowords (18-bit!) to the then very extravagant 16 kilowords. We also investigated the use of microprocessors in embedded systems at a comparatively early date. In 1972 Hilding Elmqvist and Lennart Nilsson worked with the Intel 4004 processor, which was new at the time. A major reason for our early interest in real-time systems and embedded systems was Karl Johan Åström's background from IBM.

In 1971 Prof James D. Schoeffler from Case Western Reserve University was invited to give a PhD course on "Hardware and Software for Real-Time Computers" for our graduate students. This course formed the base for a Master level course called "Computers in Control Systems" that was developed by Johan Wieslander and first given in 1973. A succession of lecture notes were generated and published in the book *Datorn som systemkomponent – uppbyggnad, programmering och exempel på processtyrning* (The Computer as a system component—design, programming, and examples of process control), published in 1977. The primary tool for the teaching was the PDP-15. We had very good assistance from Digital Equipment who provided us with early releases of their real time operating system RSX. In one of the laboratory experiments in the course a DDC (Direct Digital Control) package was implemented on the PDP-15. An early example of an industrial real-time control application at the department was an iron ore crusher application located at LKAB in Kiruna in northern Sweden. The process was controlled by a self-tuning controller running on the PDP-15 computer in Lund, some 2000 kilometers away, via a telephone modem. The sampling interval was two minutes.

The laboratory was enhanced with the acquisition of five LSI-11 in 1977. The systems were provided with the floppy disk-based operating

system RT-11, a foreground/background operating system with some real-time capabilities. Based on these machines we introduced a new collection of laboratory experiments. Much software was written, a nice collection of library routines and many utility programs.

A Major Step Forward

The drawback with RT-11 from an educational point of view was that it was difficult to see in detail what goes on in a real-time operating system. A major step forward happened in 1979 when Concurrent Pascal was introduced. The first purely Pascal-based version (OMSI Pascal) of the kernel was written by Sven Erik Mattsson and Hilding Elmqvist around 1980. Sven Erik Mattsson was inspired by a meeting with the "Purdue Europe" Workshop on real-time control in 1979 and by a real-time kernel developed by Tommy Essebo and others as a project in a PhD course in 1979. Inspiration also came from the evaluation of the Ada language suggestions which we were involved with in 1978–79. Elmqvist also gained experience as a postdoc at Stanford University in 1978–1979. At this time such kernels were typically written completely in assembly. Our kernel was implemented in two layers. The upper API layer contained process creation, semaphores, mailboxes, priority handling and scheduling. It was written in Pascal relying on the lower machine oriented layer consisting of about 100 machine instructions for process creation, context switch and interrupt handling. This structuring of the code and the corresponding documentation was of great benefit when teaching the complex sequences of events in a real-time kernel.

Starting in 1979 the course "Computers in Control Systems" was split in two parts. The emphasis in "Computers in Control Systems I" was on understanding and usage of computer control system. The course was given primarily for chemical and mechanical engineers. The course "Computers in Control Systems II" focused on implementation of computer control systems, real-time systems, and concurrent programming. A new version of the latter course was developed by Hilding Elmqvist. This course was primarily aimed at students with a background in elec-

Figure 7.1 The ball and beam laboratory process

tronics and computers. Elmqvist did on-line demonstrations in his lectures and he also introduced a new set of laboratory experiments based on the ball and beam laboratory process shown in Figure 7.1. Elmqvist together with Mattsson and Gustaf Olsson also wrote the new textbook for the course, *Datorer i Reglersystem*. Leif Andersson also took very active part in writing and he gradually took over the development of the kernel. The arrival of the "semi-portable" LSI-11s together with an easy-to-use software environment made it possible for us to make experiments at other laboratories and in industry. A number of master science theses were performed in this way.

The separation in two courses was maintained until 1987 when Gustaf Olsson, then responsible for "Computers in Control System I," was pro-

moted to professor at the the Department of Industrial Automation. The course was transfered to his department, where it was expanded and renamed "Computers in Automation." Gustaf Olsson later wrote the textbook *Computer Systems for Automation and Control*, co-authored by Gianguido Piani and published by Prentice-Hall in 1992.

New Directions

During the 1980s and 1990s a number of different software and hardware platforms were used in the course. In 1983 we started using IBM PCs and Modula-2. The real-time kernel was ported to Modula-2 and executed in native mode under MS-DOS. A simple windowing system was also developed. At the same time the name of the "Computers in Control System II" course was changed to "Applied Real-Time Programming." Around 1985 we changed to IBM PC ATs (Intel 286).

The next major event in the course happened in 1986. At that time Boris Magnusson at the Department of Computer Science started teaching the course "Real-Time Programming" and it was decided that this course should be a mandatory prerequisite for the students of "Applied Real-Time Programming." Just before that Hilding Elmqvist had left the department and joined SattControl, and the course responsibility was now taken over by Lars Nielsen and Per Hagander. The course was focused on industrial robots for some years. This coincided with the acquisition of an ASEA industrial robot in the laboratory. In 1989 we started, in parallel with the PC platforms, to use a host-target environment based on Sun and Motorola 68020. To support this the kernel was ported to the Motorola 680X0 architecture and, later on, also to Sun Solaris. The kernel was now implemented in C and the application programs, still written in Modula-2, were automatically translated into C. With the C basis it was subsequently also possible to support C++. This version of the kernel was developed by Anders Blomdell. New course material was developed by Lars Nielsen and the course again changed name, now to "Computer Implementation of Control Systems."

Lars Nielsen left the department in 1991 and Ola Dahl took over course responsibility for one year, before Karl-Erik Årzén became responsible in 1993. It was decided that the course "Real-Time Programming" should no longer be a prerequisite for our course, which again changed name, now to the current name "Real-Time Systems." During 1993–1997 several new elements were introduced in the course, e.g., scheduling theory, monitoring and diagnosis, synchronous real-time languages, Petri nets, fuzzy control, implementation of state machines and Grafcet, etc. In 1996 the first part of a new course material, *Real-Time Control Systems*, developed by Karl-Erik Årzén was introduced. During the 1990s we also introduced 486, and Pentium-based PCs, and upgraded the VME environment to 68040. In 1996 Anders Blomdell ported the kernel to Windows NT. InTouch from Wonderware Corp. and Java were used for developing graphical user interfaces.

Teaching Philosophy

The goal for our teaching in real-time systems has always been to give the students a thorough understanding of how real-time control systems are implemented. In order to do this it is important that the students get hands-on experience with real-time control system implementation. This has been achieved via course projects. The students do projects in groups of two to four. The projects last around two weeks. In the beginning of the 1980s the projects were highly standardized. The students could chose among three projects: controller implementation (Regul), operator communication (Opcom) and computer-computer communication (Datcom). All were performed within the context of the ball and beam process. Today the students have 30 projects to choose from. The character of the projects ranges from control system implementation to real-time kernel improvements. It is also possible to do joint course projects with the course in Adaptive Control.

Another goal in the teaching has been to show how a real-time kernel is implemented. That is the main reason why we always have used our own real-time kernels. Because of this we can show the students all the

software layers down to the assembly code that performs the context switching. Using commercial kernels it is either not possible to show this, or the code is not suitable for teaching purposes.

The kernel that we are using now runs on a large number of platforms. The kernel is a shared address space kernel that uses priority-based preemptive scheduling. It contains interprocess communication primitives that support semaphores, monitors with priority inheritance and condition variables, and asynchronous message passing. The kernel is flexible and can be easily modified. For example, in course projects the scheduling strategy has been changed to earliest deadline first (EDF) scheduling without any problems. The priority ceiling protocol for resource allocation has also been implemented.

Graduate Courses

Real-time system has been the subject of several PhD courses over the years. In 1979 the course Modern Languages for Process Control was held. The course projects in that course resulted in the development of the real-time kernel.

In 1978–79 the department together with the National Defense Research Institute (FOA) participated in the evaluation of the yellow, blue, red, and green languages of which the green language won and became known as Ada. Sven Erik Mattsson attended the Ada Test and Evaluation Workshop in London in 1979. The same year he made a presentation at two information meetings on Ada for industry arranged by FOA. A four-day Ada course was given in May 1983 by Svante Jahnberg, Jonas Agerberg, and Lennart Månsson from FOA. The next year a regular graduate course on Ada was given. Experiments were also performed with Ada in the real-time systems course. The Ada courses were organized within the context of an application study on Ada for program design performed by Svenska Mekanförbundet that Leif Andersson and Karl Johan Åström participated in.

At the end of the 1980s we also investigated the potential of using C++ as a real-time language. A small foreground-background scheduler was

implemented in C++ by Dag Brück. Brück later became a member of the ANSI and ISO C++ standardization committees. In 1990 we hosted meetings of the ISO and ANSI C++ committees. In connection with this an advanced C++ course was given together with a seminar series including presentations by Bjarne Stoustrup and Andy Koenig. Although C++ never played any major role in our teaching it became used in our research projects on robotics and computer aided control systems design.

A number of other graduate courses on real-time systems have also been given. A course on Theories of Real-Time Languages was held in May 1984 by Björn von Sydow, then with Umeå University. In 1996 Bo Sandén from George Mason University held a three-day course in Design of Concurrent Systems with the focus on software engineering principles for real-time systems. The new version of Ada, Ada 95, was used for the examples. A study circle on Real-Time and Fault-tolerant Systems was held in 1997.

In August 1997 we organized the "Real-time Week in Lund" (Realtidsveckan i Lund). The event contained three parts: the official inauguration day for ARTES, an SSF-funded national research network and graduate school on real-time systems; a one-day tutorial on real-time systems given by Prof John Stankovic; and SNART 97, the Swedish conference on Real-Time Systems containing two day paper presentations, a poster session, and an industrial exhibition. The conference was a great success with around 170 participants and 11 industries participating in the exhibition.

Research

Real-time systems are an important part of the research performed at the department. Already in the beginning of the 1970s we were involved with the development of real-time control system languages for heating, ventilation and air-conditioning systems (HVAC). In 1980–1981 Sven Erik Mattsson made a study of how Ada influenced and supported the design and architecture of a control system. An important conclusion was that communication between processes was complicated.

The STU-funded Center for Industrial Computer Systems (CID) was started in 1980 together with the Department of Computer Engineering. One of the most important results of this was the project LICS—Languages for Implementation of Control Systems. The project, led by Hilding Elmqvist, developed a language and interactive environment for implementation of control systems and dynamic modeling. Graphics were used to represent hierarchical structures, interconnections and interfaces. Low level modules were described by equations. The project introduced the concept of information zooming. The project ended in 1985 when Elmqvist joined SattControl (now Alfa Laval Automation). At SattControl the ideas behind LICS were used in the developed of the SattGraph graphical user interface and the SattLine distributed PLC system.

The laboratory for robotics and visual sensory control was initiated in 1986 by Lars Nielsen, who did his PhD thesis on visual servoing in 1985. The basis for this was the ASEA (now ABB) Irb-6 robot donated by ASEA. In 1987 Klas Nilsson from ABB Robotics started as a PhD student. This strengthened the contacts with ABB and also resulted in the acquisition of an ABB Irb-2000 robot in 1992. In 1992 Ola Dahl presented his PhD thesis on robot path following. This was followed in 1996 by Klas Nilsson's PhD thesis where he presented an open software architecture for robotics control. The robotics laboratory has also been used by Rolf Johansson for work on adaptive control, force feedback, and identification.

In the robot control system the ABB control system was replaced by an hardware architecture consisting of VME-bus based 680X0s and digital signal processors (DSP). A small real-time kernel was developed for the DSPs. DSPs had then been used at the department for some time. In 1985 Hans Hanselmann, later the founder or dSPACE, held a seminar series on digital signal processors and implementation of fast digital controllers. An implementation of a PID controller on National Instrument DSP board equipped with a Texas TMS DSP running under a Macintosh was done in 1992. The system could run an adaptive controller at 2 kHz sampling interval.

Around 1984 the department started to evaluate Artificial Intelligence techniques for real-time control applications. In the STU-funded expert control projects led by Karl-Erik Årzén the goal was to extend the functionality of feedback controllers by encoding knowledge about autotuning, adaptation, and control loop supervision in a knowledge-based systems supervising numerical algorithms for control, identification, and monitoring. Similar ideas have later been pursued under the name autonomous control. The department was one of the first external users of the real-time expert system tool G2 from Gensym Corp in 1987. Since then G2 has been used in a large number of projects in supervisory real-time control, e.g., monitoring and diagnosis and recipe-based batch production.

Rapid implementation of control algorithms has always been something that we have strived for. One example of this is the Sim2DDC package developed by Ola Dahl. In Sim2DDC control algorithms were expressed in the Simnon modeling language. From this Modula-2 code was automatically generated. A later system in the same spirit is the Pålsjö environment developed by Johan Eker and Anders Blomdell. Here continuous or discrete control algorithms are expressed in the PAL language. From this C/C++ code is automatically generated.

The department has also performed research in the intersection between control and real-time systems. Within the NUTEK project DICOSMOS, Johan Nilsson, Bo Bernhardsson, and Björn Wittenmark are looking upon the influence of communication delays on control loops closed over a distributed system.

The Future

Currently the prospects for real-time systems research are more promising than ever. We participated in the formulation of the ARTES research network and graduate school that was approved by SSF (Stiftelsen för Strategisk Forskning) in 1997. The volume of the network is 5 MSEK/year with an anticipated expansion to 15 MSEK/year after two years. The network supports research projects, a coordinated national graduate school in real-time systems, and mobility.

In the first ARTES call for proposals in November 1997 a project proposal from the department on Integrated Control and Scheduling was approved. The project is based on a interesting collaboration with Dr Lui Sha at the Software Engineering Institute, Carnegie Mellon University. Lui Sha is one of the developers of the generalized rate monotonic scheduling theory. Other partners in the project are the Department of Computer Science, LTH, and Sigma Exallon Systems AB. The project will begin in April 1998.

8. Dissertations

One PhD dissertation and three Lic Tech theses were defended during 1997. The abstracts are presented here in chronological order.

Comparison and Simplification of Uncertain Models

Lennart Andersson
Lic Tech dissertation, January 28, 1997

Mathematical models describing the behavior of physical systems are important in many areas. The required accuracy of the model largely depends on the purpose for which the model is intended.

In control engineering there is usually a trade off between model simplicity and model accuracy. Simulation and controller design based on complex models may result in time consuming computations, numerical difficulties and a designed controller which usually is complex and therefore may be expensive and difficult to implement. Models with low accuracy, on the other hand, may give rise to incorrect simulations, as well as control loops with low performance or even instability.

For these reasons there is a need to use a hierarchy of models, each equipped with a quality measure. The most appropriate should then be used for each task. Computation of such quality measures is the objective of this thesis. We analyze the importance of different components in a model. We then simplify the description of the less important components to a suitable level of accuracy. The resulting model is obtained together with a quality measure. This approach is a generalization of the Balanced truncation method for linear time-invariant models.

The components in the model may contain dynamics, nonlinearities and uncertainty and are described using integral quadratic constraints. The information captured by such constraints allows us to calculate positive values to each of the components, such that the simplification error always is bounded by the sum of these values for the simplified components. The computations are based on convex optimization and the bound is defined in terms of the induced 2-norm.

Recipe-Based Batch Control Using High-Level Grafchart

Charlotta Johnsson
Lic Tech dissertation, June 6, 1997

High-Level Grafchart is a graphical programming language for control of sequential processes. Sequential control is important in all kinds of industries: discrete, continuous and batch. Sequential elements show up both on the local control level and on the supervisory control level.

High-Level Grafchart combines the graphical syntax of Grafcet/SFC with high-level programming language constructs and ideas from High-Level Petri Nets. High-Level Grafchart can be used to control sequential processes both on the local level and on the supervisory control level.

The main application area of High-Level Grafchart is control of batch processes, i.e., batch control. A batch process is a special class of sequential processes frequently occurring in chemical, pharmaceutical and food industries. Batch processes and batch control is currently the subject of large interest. A recent standard, called ISA S88.01, provides an important step towards a formal definition of batch systems. The specification of how to produce a batch is called a recipe.

In the thesis it is shown how High-Level Grafchart can be used for recipe structuring. By using the features of High-Level Grafchart in different ways, recipes can be represented in a number of alternative

ways. They still however, comply with the standard ISA S88.01. The different structures are presented and discussed. A simulation of a multi-purpose, network structured batch plant has served as a test platform. High-Level Grafchart, the recipe-execution system and the batch plant are implemented in G2, an object-oriented programming environment.

A Framework for Dynamically Configurable Embedded Controllers

Johan Eker
Lic Tech dissertation, November 12, 1997

Embedded control systems are today created using tools that give insufficient support for rapid prototyping and code reuse. New tools for implementation of embedded controllers are necessary. This thesis presents a software framework for implementation of embedded control systems. A new language PAL is presented. PAL is designed to support implementation of control algorithms in particular. A run-time system called Pålsjö is also introduced. Algorithms written in PAL may be executed in the Pålsjö system. The Pålsjö system is designed to allow on-line system configuration and reconfiguration.

Three new software patterns are identified and documented. One pattern describes a way to execute control algorithms on block diagram form. Another pattern deals with the problem of assigning parameters to controllers. A third pattern describes a way to add new objects to a pre-compiled framework.

The thesis contains five case studies in which different aspects of the PAL language and the Pålsjö system are demonstrated.

Relay Feedback and Multivariable Control

Karl Henrik Johansson
PhD dissertation, November 25, 1997

Opponent: Prof Hendrik Nijmeijer, University of Twente, The Netherlands. Committee: Prof David Mayne, London; Prof Torkel Glad, Linköping; Dr Lars Pernebo, Alfa Laval Automation, Malmö.

This doctoral thesis treats three issues in control engineering related to relay feedback and multivariable control systems.

Linear systems with relay feedback is the first topic. Such systems are shown to exhibit several interesting behaviors. It is proved that there exist multiple fast relay switches if and only if the sign of the first non-vanishing Markov parameter of the linear system is positive. It is also shown that these fast switches can appear as part of a stable limit cycle. A linear system with pole excess one or two is demonstrated to be particularly interesting. Stability conditions for these cases are derived. It is also discussed how fast relay switches can be approximated by sliding modes.

Performance limitations in linear multivariable control systems is the second topic. It is proved that if the top left submatrices of a stable transfer matrix have no right half-plane zeros and a certain high-frequency condition holds, then there exists a diagonal stabilizing feedback that makes a weighted sensitivity function arbitrarily small. Implications on control structure design and sequential loop-closure are given. A novel multivariable laboratory process is also presented. Its linearized dynamics have a transmission zero that can be located anywhere on the real axis by simply adjusting two valves. This process is well suited to illustrate many issues in multivariable control, for example, control design limitations due to right half-plane zeros.

The third topic is a combination of relay feedback and multivariable control. Tuning of individual loops in an existing multivariable control

system is discussed. It is shown that a specific relay feedback experiment can be used to obtain process information suitable for performance improvement in a loop, without any prior knowledge of the system dynamics. The influence of the loop retuning on the overall closed-loop performance is derived and interpreted in several ways.

9. Honors and Awards

The Nordic Process Control Award was presented to Professor **Karl Johan Åström** at the 7th Nordic Process Control Workshop in Wadahl, Norway, on January 13, 1997. The award is presented to persons who have made a lasting and significant contribution to the field of process control. This was the second time the award was presented. In 1995 the award was given to Professor Howard H. Rosenbrock.

Björn Wittenmark was elected member of Kungliga Fysiografiska Sällskapet (Royal Physiographic Society) in Lund, April 1997.

Anders Rantzer was elected as Senior Member of IEEE on May 3, 1997.

Jörgen Malmborg received the 1997 *Scania Scholarship* for his work on hybrid control systems in May 1997.

Professor **Karl Johan Åström** was given an award at SYSID'97, the 11th IFAC Symposium on System Identification, in "recognition and appreciation of his continuous and outstanding contribution to the series of IFAC symposia on System Identification." July 9, 1997.

On November 26 **Tore Hägglund** recieved an award from *Innovation Cup* for the contribution "Automatic supervision of automation systems." Innovation Cup is sponsored by Skandia and Dagens Industri.

Bo Bernhardsson and **Anders Rantzer** received an honorable mention in the SIAM Activity Group on Linear Algebra Prize for their paper "A Formula for Computation of the Real Stability Radius" (joint with Qiu, Davison, Young, and Doyle).

On December 4, **Anders Rantzer** received a Junior Individual Grant from the Foundation for Strategic Research. This was one out of ten grants awarded to young Swedish researchers in science, technology and medicine.

On December 10 **Karl Johan Åström** was elected as Foreign Member of the Russian Academy of Natural Sciences.

10. Personnel and Visitors

Personnel

During 1997 the following persons have been employed at the department. The list shows the *status of December 1997* if nothing else is mentioned.

Professors

Karl Johan Åström
Per Hagander (biträdande)
Jan Sternby (adjungerad) *(adjunct 20%from July 1)*
Björn Wittenmark

Associate Professors

Tore Hägglund
Rolf Johansson

Research Associates

Karl-Erik Årzén
Bo Bernhardsson
Sven Erik Mattsson
Bernt Nilsson *(left the department June 30)*
Anders Rantzer

Research Engineers

Leif Andersson
Anders Blomdell
Rolf Braun
Tomas Schönthal

PhD Students

Lennart Andersson
Anna Delfin *(from April)*
Jonas Eborn
Johan Eker
Mattias Grundelius
Magnus Gäfvert
Sven Hedlund *(from March)*
Karl Henrik Johansson *(PhD Nov 1997)*
Mikael Johansson
Charlotta Johnsson
Ulf Jönsson *(PhD Nov 1996, stayed until July 1)*
Jörgen Malmborg
Erik Möllerstedt
Johan Nilsson
Hélène Panagopoulos
Mikael Petersson *(from March)*
Anders Robertsson
Lars Malmcolm Pedersen *(from April)*
Anders Wallén
Mats Åkesson
Martin Öhman

Secretaries

Eva Dagnegård
Britt-Marie Mårtensson
Eva Schildt
Agneta Tuszynski (part time)

Temporary Appointments

Helena Andreas (June–July)
Birgitta Nilsson, librarian (January–June)
Michael Lantz (half time, November–December)

Visiting Scientists

The following researchers have stayed with the department for about a week by the least.

Rod Bell *December 8, 1996 – January 30, 1997*
Macquarie University, School of Mathematics and Physics, New South Wales, Australia

Pericles Barros *September 16 – February 28, 1997*
Universidade Federal da Paraiba, Departamento de Enghenharia Elétrica, Campina Grande, Brazil

Robert van der Geest *February 19–28, 1997*
University of Twente, Systems and Control Group, Enschede, The Netherlands

Romeo Ortega *April 6–15, 1997*
Laboratoire des Signaux et Systemes, CNRS-ESE, Gif sur Yvette, France

Andrey Barabanov *January 7 – April 27, 1997*
St Petersburg State University, St Petersburg, Russia

James Sørlie *September 2, 1996 – June 30, 1997*
Royal Institute of Stockholm, S3—Automatic Control, Stockholm, Sweden

Sven Kathri *March 24 – May 23, 1997*
Caltech, Pasadena, USA

Richard Murray *June 25–29, 1997*
California Institute of Technology, Pasadena, California

Paolino Tona *July 18 – October 4, 1997*
ENSIEG, Lab d'Automatique de Grenoble, France

Daniel Pagano *August 4 – September 3, 1997*
Universidad de Sevilla, Depto de Ingenieria de Sistemas y Automatica, Sevilla, Spain

Liankui Dai *September 1, 1997 – May 31, 1998*
Institute of Industrial Process Control, Zhejiang University, Hangzhou, P.R. China

Federico Cuesta *September 1 – October 31, 1997*
Universidad de Sevilla, Depto de Ingenieria de Sistemas y Automatica, Sevilla, Spain

Jan Komorowski *September 1, 1997 – April 30, 1998*
Knowledge Systems Group, Dept of Computer and Information Science, Norwegian University of Science and Technology, Trondheim, Norway

Per Brath Jensen *September 1 – December 31, 1997*
Danfoss Drives A/S, (Aalborg University)

Joel Chebassier *September 6–12, 1997*
ENSIEG, Lab d'Automatique de Grenoble, France

Mohammed m'Saad *September 6–12, 1997*
Process Control Lab, Caen, France

Jan Bergstrom *September 29 – October 6, 1997*
University of British Columbia, Pulp and Paper Centre, Canada

Visiting Students

The following foreign students have stayed with the department and and followed the courses. Many of them have made their master's theses. Students marked with "(E)" are from the ERASMUS program, "(B)" are from bilateral agreement.

Pablo Tapia Lopéz *February 11 – August 11, 1997*
Engineering in Automatica and Industrial Electronics Politecnica University of Valencia, Spain

Sabina Brufani (E) *June 18, 1996 – February 21, 1997*
Universita di Roma "La Sapienza",
Departimento di Informatica e Sistemistica, Rome, Italy

Valon Recica *June 16, 1997 – February 1998*
Uppsala University, Automatic Control, Uppsala, Sweden

José Luis Guerra da Rocha Nunes (E) *October 2, 1996 – August 9, 1997*
Univ of Coimbra, Informatic Department,
Coimbra, Portugal

Martin Rentsch (B) *October 27, 1997 – March 13, 1998*
ETH, Zürich, Switzerland

Ben Bastian (B) *December2, 1997 – March 30, 1998*
Univ of Newcastle, Australia

11. Staff Activities

This is a short description of the research staff (listed in alphabetic order) and their activities during the year. Publications and lectures are listed in separate sections.

Andersson, Lennart

Lic Tech, graduate student since 1993. His research interest is modeling of nonlinear and uncertain systems. During 1997 he presented his Licentiate thesis "Comparison and Simplification of Uncertain Models" and was a teaching assistant in the engineering courses on Automatic Control, Adaptive Control, and Nonlinear Control.

Åkesson, Mats

MSc, graduate student since 1994. His main research interest is modeling and control of biotechnical processes. Currently, he is working together with Per Hagander on control of fed-batch units with genetically modified *E. coli* on a contract with Pharmacia & Upjohn. Experimental work has been performed in collaboration with the Department of Biotechnology, Lund University. During 1997, Mats has been a teaching assistant in the courses Computer-Controlled Systems and Automatic Control, basic course.

Årzén, Karl-Erik

Research associate, PhD (1987): Joined the department in 1981. His research interests are Petri nets and Grafcet, monitoring and diagnosis, fuzzy control, and real-time systems.

In March 1997 he spent two weeks as a guest researcher with Software Engineering Institute, Carnegie Mellon University. In August 1997 he organized the "Real-Time Week in Lund" (Realtidsveckan i Lund) consisting of the official inauguration of ARTES, an SSS-funded research network on real-time systems; a one-day tutorial by Professor

John Stankovic on real-time systems; and SNART 97, the Swedish real-time systems conference with two days of paper presentation, a poster session, and an exhibition.

During the year he has been working in the ITM project and the FAMIMO project on fuzzy control, in the NUTEK-REGINA project on Grafcet and recipe-based batch control, and in the TFR project on monitoring and diagnosis. He has been involved in the completion of two Licentiate theses: by Charlotta Johnsson and by Johan Eker. During fall he teached the undergraduate course on Real-Time Systems and during spring he led a graduate course on Fault-Tolerant Real-Time Systems.

Åström, Karl Johan

Professor since 1965 and head of the department. Karl Johan is interested in a broad range of control problems such as adaptive control, stochastic control, computer control, hybrid systems, and autonomous control. This year his research has been focused on friction modeling and compensation, systems with switching, and autonomous control. He has also been involved with the development of new laboratory experiments and educational software. He gave a course on Control Paradigms for PhD students. He is also responsible for the course on Adaptive Control given in the engineering program.

During the year he participated in the European Control Conference, in Brussels, the IFAC Symposium on System Identification in Kyoshu, and the IEEE Conference on Decision and Control in San Diego. He also participated in several ESF COSY meetings and in a Workshop on Virtual Engineering at Caltech.

Bernhardsson, Bo

PhD, research associate at the department since 1993. Bo is interested in linear system theory, realtime control issues and hybrid control. During this year he has worked together with the PhD students Malmborg, Möllerstedt, and Nilsson on topics described in Section 5. Bo was responsible for the LTH introduction programme 1997 for engineering physics students. During fall he gave a graduate course on Hybrid Control.

Delfin, Anna

MSc, graduate student since September 1997. Anna is interested in modeling, and currently working in the project "Dynamic modeling of an ecocyclic pulp bleaching plant." She has been a teaching assistant in Automatic Control for engineers.

Eborn, Jonas

MSc, graduate Student since 1995. Interested in computer aided control engineering, physical system modelling and numerical analysis. Jonas is working in the NUTEK programme "Complex Technical Systems" and is also involved in the collaboration with Sydkraft AB. He was a teaching assistant in the engineering courses Automatic Control and System Identification.

Eker, Johan

Licentiate of Technology in November 1997, graduate student since January 1995. Johan's main research areas are real-time control systems and embedded system. In December he spent some days in USA, visiting Kestrel Institute in Palo Alto and Integrated Systems in Sunnyvale. He has been a teaching assistant in the two basic courses in Automatic Control for engineers.

Gäfvert, Magnus

MSc, graduate student since July 1996. Magnus is interested in control systems in general, and in topics on distributed control systems in particular. He is currently working on modeling, analysis and control of systems with friction. He is also involved in the development of the computer based interactive learning tools for control education, ICTools. During the year he was a teaching assistant in Automatic Control for mechanical engineers and in Real-Time Systems.

Grundelius, Mattias

MSc, graduate student since January 1996. He is interested in Control in general and works with optimal control of packaging machines in a collaboration with Tetra Pak. He has also been a teaching assistant in the basic course for the mechanical engineers and in the course on Real-Time Systems.

Hagander, Per

Associate professor, PhD (1973). Per has been with the department since 1968 and works with linear system theory and with applications in biotechnology and medicine. He is the director of studies at the department. Per is also responsible for the course on Automatic Process Control for chemical engineers. During the fall he gave two graduate courses on Linear Systems. Since May 1996 he is leading a project with Pharmacia & Upjohn, on multivariable control of genetically engineered *E. coli*. Here Per works with Mats Åkesson.

Hägglund, Tore

Associate Professor, PhD (1984). Tore has been at the department since 1978 except for four years when he worked at SattControl Instruments AB. He is responsible for the economy at the department and for the two basic courses in Automatic Control in the engineering program. His main research interests include process control, PID control, adaptive control, supervision, and detection.

During the year Tore has participated in the NUTEK project "Autonomous Control." His main research activities have been design of PID controllers and development of new supervisory functions for process control. He also gave a course on Autonomous Control for PhD students.

Hedlund, Sven

MSc, graduate student since March 1997. Sven is interested in control in general. He has been working in the FAMIMO project implementing a Matlab tool for the analysis of piecewise linear systems. He has been a teaching assistant in the basic courses in Automatic Control for engineers.

Johansson, Karl Henrik

Research associate, PhD (1997). He has been at the department since 1992 and defended his thesis "Relay feedback and multivariable control" in November 1997. Therein he investigates properties of relay feedback systems, performance limitations in decentralized control systems, and automatic tuning of multivariable controllers. Karl Henrik

stayed three weeks at the Centre for Process Systems Engineering at Imperial College in London and the Control Systems Centre at UMIST in Manchester, January–February 1997. Karl Henrik is involved in two industrial projects: one on modeling and control of a deaeration process with Tetra Pak Food & Beverage Systems AB in Lund and one on HVDC control with ABB Power Systems AB in Ludvika. He was a teaching assistant in the engineering course System Identification.

Johansson, Mikael

MSc, PhD student since 1994. His research interests include modeling and analysis of nonlinear and hybrid control systems. He has been working in the ITM project "Design and Tuning of Fuzzy Controllers based on Nonlinear Control Theory." Mikael has also been involved in the development of interactive learning tools for control: ICTools. During 1997, Mikael has been a teaching assistant in the course Nonlinear Control and Servo Systems and the basic course Automatic Control.

Johansson, Rolf

Associate professor, MD, PhD, active at the department since 1979. Rolf Johansson's research interests are in system identification and in robotics and nonlinear systems. He is responsible for the two courses System Identification and Nonlinear Control and Servo Systems in the engineering program.

Rolf is coordinating director for a NUTEK-sponsored research program "Lund Research Programme in Autonomous Robotics" with cooperation partners from Dept Production and Materials Engineering and Dept Industrial Electrical Engineering and Automation and industrial partners. Together with Dr. Måns Magnusson he leads research at the Vestibular Laboratory, Dept. Otorhinolaryngology, Lund University Hospital. From June 9 to July 8 he visited California Institute of Technology in Pasadena, California, USA.

Johnsson, Charlotta

Lic Tech, graduate student since 1993. She is interested in supervisory control with focus on batch recipe management. She is currently

working in the NUTEK project "High-Level Grafcet for Supervisory Sequential Control." Her teaching assignments have been the two courses System Identification and Automatic Control in the engineering program.

During 1997 she visited Ecole Nationale Supérieure d'Ingénieurs Electriciens de Grenoble, France, for three weeks, where she worked with Professor R. David and Professor H. Alla.

Jönsson, Ulf

PhD. Ulf joined the department in 1990 and finished his PhD thesis in November 1996. His research has been directed towards the development of methods for robustness analysis of nonlinear and uncertain systems. He has been involved in the project "Control of Uncertain Systems." From January to July 1997 he visited California Institute of Technology. He is now a postdoctoral scholar at Laboratory for Information and Decision Systems at Massachusetts Institute of Technology.

Malmborg, Jörgen

MSc, DEA, graduate student since 1991. His research interests are modeling and analysing of switched and hybrid control systems. He is working within the project on hybrid control systems and from spring 1995 he is involved in the REGINA project "Heterogeneous Control of HVAC Systems." Lately his research has been focused on solution and simulation of discontinuous differential equations. These problems appears frequently in hybrid systems. Jörgen has also been a teaching assistant in the engineering courses Automatic Control and Automatic Process Control.

Mattsson, Sven Erik

Research associate, PhD (1985). Joined the department in 1976. He is responsible for the research activities in computer aided control engineering (CACE). His research interests include methods and tools for development and use of mathematical models.

Mattson is an active member of the Modelica design team since its conception in September 1996. He is the project leader for the NUTEK

project "Modeling and Simulation of Complex Systems," which is a part of NUTEK's research program "Complex Systems." He is also the project leader for the project "Modeling and Control of Energy Processes," which is a collaboration with Sydkraft Konsult AB. It is funded by Sydkraft AB. He supervises another two PhD projects "Modeling of Electricity Distribution Networks and Components" and "Dynamic Modeling of an Ecocyclic Pulp Bleaching Plant."

Möllerstedt, Erik

MSc, graduate student since 1994. His research interests are analysis, modeling, simulation and control of non-linear systems. He is currently working in the ELEKTRA project "Modeling of Electricity Distribution Networks and Components" sponsored by Elforsk and NUTEK. Erik has been a teaching assistant in the engineering courses Adaptive Control and Computer-Controlled Systems.

Nilsson, Johan

Lic Tech in May 1996, graduate student since 1992. His research interests concerns both theory and applications. The major research area is in the field of timing problems in real-time systems. Johan has been a teaching assistant in the courses Real-Time Systems and Computer-Controlled Systems in the engineering program.

Öhman, Martin

MSc, graduate student since January 1996. Martin is interested in modelling and model reduction of nonlinear systems. He is also working with the PLC programming standard IEC 1131. He has been a teaching assistant in the engineering courses Automatic Control and Automatic Process Control.

Panagopoulos, Hélène

Msc, graduate student since September 1995, whose research interests concern both theory and applications. The major research area is in the field of PID-controller design.

Pedersen, Lars Malcolm

Lars Malcolm Pedersen has been working at the Department of Automatic Control from 1992 to 1995 in connection with an industrial research project concerning thickness control for hot rolling mills. He is now back for a two year period from 1997 to 1999 and he now works with temperature control of reheat furnaces. Lars has been an employee of The Danish Steel Works Ltd., Frederiksværk, Denmark, since 1991. For the time being he works half time on the Steel Work and half time on the Department. Among is research interests are modeling, system identification, and nonlinear control all applied to real systems in the steel industry.

Petersson, Mikael

MSc, graduate student since 1997. Petersson is an industrial PhD-student employed by ABB Corporate Research. His research interests include monitoring and diagnostics of industrial processes, and applying and evaluating advanced theory in this area.

Rantzer, Anders

Research associate, PhD (KTH 1991). Joined the department in 1993 after a postdoc position at IMA, University of Minnesota. Research interests are in modeling, analysis and design of control systems, particularly the effects of uncertainty and nonlinearities.

This year he has supervised students in the projects “Nonlinear and Uncertain Systems”, “Modeling with Quantified Accuracy,” “Multi-Loop Control Systems,” “Switching Systems” and “Piecewise Linear and Fuzzy Control.”

Robertsson, Anders

PhD student, joined the department in 1993. Anders’ current research is in nonlinear control and robotics. He is involved in the NUTEK project “Lund Research Programme in Autonomous Robotics.” He has been a teaching assistant in the basic engineering course on Automatic Control.

During the period March 10 – April 5, 1997, Anders Robertsson visited professor H. Nijmeijer, the Systems and Control Group, TU Twente,

The Netherlands. In October he visited Twente again for another week and participated in the dissertation procedure of Robert van der Geest.

Sternby, Jan

Part-time (20%) adjunct professor. He took his PhD at the department in 1977 and left in 1980 to work in industry. He is currently working in the Therapy Research group at Gambro AB in Lund. Jan Sternby spent 11 years as a part-time (25%) adjunct professor of automatic control at Luleå Technical University, where he supervised PhD students in the areas of anti-windup methods, control of systems with periodic disturbances, and crane control. His research interests also include adaptive control and all aspects of modelling in dialysis. He has developed a new course, Project in Control, which is part of the Master's program at the department.

Wallén, Anders

MSc, graduate student since 1991. His main research interests are control loop supervision and software design of control systems. He is working in the NUTEK project "Autonomous Control." During the year he has developed two new laboratory exercises used in the engineering course on Computer-Controlled Systems He was also a teaching assistant in that course as well as in the basic course on Automatic Control.

Wittenmark, Björn

Professor in Automatic Control since 1989. He joined the department in 1966 and took his PhD in 1973. His main research interests are adaptive control, sampled-data systems, and process control. He is working within the projects "Rolling Mill Control", "Timing Problems in Real-time Systems", and "Dynamic Modeling of an Ecocyclic Pulp Bleaching Plant." He is also very active in developing learning tools for the courses in control, especially the course Computer-Controlled Systems, which he also teaches.

Apart from his work at the department he is also Deputy Dean of Lund Institute of Technology.

External Assignments

Opponent and Member of Examination Committee

Karl-Erik Årzén: Opponent for Hassan Yazdi's PhD thesis, DTU, May 1997. Member of the examination committee at the PhD dissertation of Johan Gunnarsson at LiTH, May 1997. Opponent for Tormod Drengstig's PhD thesis, NTNU, Trondheim, November 1997.

Bo Bernhardsson: External examiner for a Master thesis in Halmstad, January 1997.

Per Hagander: Opponent for Eric Beran's PhD thesis, DTU, December 1997.

Tore Hägglund: Opponent for Mats Friman's PhD thesis, "Extensions and Modifications of Relay Autotuning," Åbo Academy, Finland, October 1997, and for Bi Qiang's PhD thesis "Frequency domain adaptive control with relay feedback," The National University of Singapore, Singapore, November 1997.

Anders Rantzer: external examiner of a PhD thesis in Trondheim, Norway, May 1997.

Jan Sternby: Member of evaluation committee at the PhD dissertation of Bengt Lindoff, "Parameter Estimation and Control of Time-Varying Stochastic Systems," LTH, September 1997.

Björn Wittenmark: Substitute member of the evaluation committee at the PhD dissertation of Magnus Akke, LTH, April 1997.

Board Member

Karl Johan Åström: Member of the Board of Mathematics, the Board of Physics, and the Board of Electrical Engineering and Computer Science, at Lund University. Chairman of Theme1 Control of Nonlinear Systems in the European Science Foundation program on Control of Complex Systems. Member of the Medal Committee of the Royal Swedish Academy of Engineering Sciences. Member of the Committee for the Chester Carlsson Prize in Information Technology, Royal Swedish Academy of Engineering Sciences. Member of the board of

the SSF Artes program. Member of the International Advisory Board for the SSF CAS project. Chairman for the Wallenberg Foundation WITAS program. Member of the Board of the NUTEK Regina program. Chairman of the COSY program of the European Science Foundation. Chairman of the Sydkraft Research Foundation.

Per Hagander: Vice-chairman of the Board of Engineering Physics program, Lund Institute of Technology, and member of the Board of University Library 2, Lund University. Member of the Computer Group of FED, and of the Promotion Board of Lund Institute of Technology.

Tore Hägglund: Member of the Education Board of Computer Science and Technology, Lund Institute of Technology.

Sven Erik Mattsson: Member of the Modelica Design Group.

Jan Sternby: Member of the Board of Engineering Physics Program, Lund Institute of Technology.

Björn Wittenmark: Deputy Dean and board member of Lund Institute of Technology. Board member of Lunds Universitets Utvecklings Aktiebolag (Lund University Development Limited). Board member of Lunds Datacentral, LDC (Lund University Computing Center).

Book and Journal Editor

Karl-Erik Årzén: Associate Editor for Automatica and Advisory Editor for Engineering Application of Artificial Intelligence.

Tore Hägglund: Associate editor for Control Engineering Practice.

Anders Rantzer: Associate editor for IEEE Transactions on Automatic Control, European Journal of Control, and Systems and Control Letters.

Björn Wittenmark: Member of Editorial Boards for Optimal Control Applications & Methods, Journal of Forecasting, and International Journal of Adaptive Control and Signal Processing.

Advisory Committees and Working Groups

Karl-Erik Årzén: Reviewer of the EU Esprit programme.

Karl Johan Åström: Chairman for the evaluation of DLR, Oberfpaffenhofen Germany, April 1997. Member of the Research Advisory Board for the LIDS Laboratory at MIT. Member of the Research Advisory Council for the Institute for Systems Research, University of Maryland.

Per Hagander: Member of IFAC Committee on Biomedical Engineering and Control. Member of IFAC Technical Steering Committee on Biomedical Engineering Control.

Mikael Johansson: Member of the IFAC Technical committee on Fuzzy and Neural Systems, and deputy member of Research Board "FIME" at Lund Institute of Technology.

Anders Rantzer: Member of the expert panel for evaluation of INTAS projects in Brussels, May 1997.

Björn Wittenmark: Swedish representative of European Union Control Association (EUCA) Council.

Member of International Program Committee (IPC)

Karl Erik Årzén: Chairman of the Programme Committee for SNART 97, Lund, 1997, and member of the International Programme Committee for the following conferences: PSE/Escape (Process System Engineering), Trondheim, Norway, 1997; ADCHEM'97 (Advanced Control of Chemical Processes, Banff, Canada, 1997; INCOM'98 (Information Control Problems in Manufacturing), Nancy, France, 1998; ADPM'98 (Automation of Mixed Processes: Dynamic Hybrid Systems), Reims, France, 1998; IFAC Workshop on On-Line Fault Detection and Supervision in the Chemical Process Industries, Lyon, France, 1998; and ICV'98 (IFAC Workshop on Intelligent Components for Vehicles), Sevilla, Spain, 1998.

Tore Hägglund: Member of the International Program Committe for the Third Portuguese Conference on Automatic Control, Coimbra, Portugal, September 1998.

Rolf Johansson: Member of the IEEE CDC/ACC Conference Editorial Board.

Sven Erik Mattsson: Program chairman for the 7th IFAC Symposium on Computer-Aided Control System Design, CACSD'97, Gent, Belgium, April 1997.

Anders Rantzer: Member of the International Program Committee for the IFAC Nonlinear Control System Design Symposium in Enschede, The Netherlands, 1998.

Other Assignments

Björn Wittenmark: Lecturer in the *Distinguished Lectures Program of the IEEE Control System Society* from 1993.

12. Publications and Conference Contributions

Two books has been finished during 1997, 3 book contributions have been published, 13 journal papers, 45 conference contributions, and 3 conference abstracts.

Books and Proceedings

Årzén, Karl-Erik, and Eva Dagnegård, Eds.: *Preprints of SNART 97—The Swedish National Real-Time Systems Conference*, Lund, Sweden, 1997. Department of Automatic Control, Lund Institute of Technology.

Åström, Karl Johan, and Björn Wittenmark: *Computer-Controlled Systems*. Prentice Hall, third edition, 1997.

Boullart, Luc, Mia Loccufier, and Sven Erik Mattsson, Eds.: *Computer Aided Control Systems Design, CACSD'97*. Pergamon, September 1997.

Hägglund, Tore: *Praktisk processreglering (Process control in practice)*. Studentlitteratur, Lund, Sweden, second edition, 1997.

Book Contributions

Åström, Karl Johan: "Fundamental limitations of control system performance." In Paulraj *et al.*, Eds., *Communications, Computation, Control and Signal Processing—A Tribute to Thomas Kailath*, pp. 355–363. Kluwer, Boston, 1997.

Branicky, Michael S., and Sven Erik Mattsson: "Simulation of hybrid systems." In Antsaklis *et al.*, Eds., *Hybrid Systems IV*, Lecture Notes in Computer Science, Vol. 1273, pp. 31–56. Springer Computer Science, July 1997.

Kuipers, Benjamin, and Karl Johan Åström: "The composition and validation of heterogeneous control law." In Murray-Smith and Johansen, Eds., *Multiple Model Approaches to Modelling and Control*, pp. 231–255. Taylor & Francis, 1997.

Journal Papers

Årzén, Karl-Erik: "AI in the feedback loop: A survey of alternative approaches." *Annual Rev. Control*, **20**, pp. 71–82, 1996. Given as a Plenary talk at the IFAC AI in Real-Time Control Workshop, Bled, Slovenia, November 1995.

Åström, Karl Johan: "Nastroĭka i adaptatsiya (Tuning and adaptation)." *Pribory i Sistemy Upravleniya (Instruments and Control Systems)*, **No 9**, pp. 53–65, 1997.

Bernhardsson, Bo, Anders Rantzer, and Li Qiu: "Real perturbation values and real quadratic forms in a complex vector space." *Linear Algebra and Its Applications*, **270**, pp. 131–154, 1997.

Fransson, P.-A., M. Magnusson, and R. Johansson: "Analysis of adaptation in anteroposterior dynamics of human postural control." *Gait and Posture*, 1997.

Hansson, Anders, and Per Hagander: "Existence of minimum upcrossing controllers." *Automatica*, **33:5**, pp. 871–879, 1997.

Holm, M., R. Johansson, J. Brandt, C. Lührs, and S. B. Olsson: "Epicardial right free wall mapping in chronic atrial fibrillation—documentation of repetitive activation with a focal spread—a hitherto unrecognized phenomenon in man." *European Heart Journal*, **18:2**, pp. 290–310, February 1997.

Jönsson, Ulf: "Stability analysis with Popov multipliers and integral quadratic constraints." *Systems and Control Letters*, **31:2**, pp. 85–92, 1997.

Jönsson, Ulf, and Anders Rantzer: "Duality bounds in robustness analysis." *Automatica*, **33:10**, pp. 1835–1844, October 1997.

Li, Z., R. J. Evans, and B. Wittenmark: "Minimum variance prediction for linear time-varying systems." *Automatica*, **33**, pp. 607–618, 1997.

Mattsson, Sven Erik, Hilding Elmqvist, and Jan F. Broenink: "Modelica: An international effort to design the next generation modelling language." *Journal A, Benelux Quarterly Journal on Automatic Control*, **38:3**, pp. 16–19, September 1997. Special issue on Computer Aided Control System Design, CACSD.

Megretski, A., and A. Rantzer: "System analysis via Integral Quadratic Constraints." *IEEE Transactions on Automatic Control*, **47:6**, pp. 819–830, June 1997.

Simensen, Jo, Charlotta Johnsson, and Karl-Erik Årzén: "A multiple-view batch plant information model." *Comput. Chem. Engng.*, **21**, 1997. Proceedings of the PSE'97/ESCAPE-7 conference, Trondheim, May 1997.

Thornhill, N. F., and T. Hägglund: "Detection and diagnosis of oscillation in control loops." *Control Engineering Practice*, **5**, pp. 1343–1354, 1997.

Conference Papers

Åkesson, Mats: "Integrated control and fault detection for a mechanical servo process." In *Proceedings of IFAC Symposium on Fault Detection, Supervision and Safety for Technical Processes*, Hull, UK, August 1997.

Åkesson, Mats, Per Hagander, and Jan Peter Axelsson: "A pulse technique for control of fed-batch fermentations." In *Proceedings of the 1997 IEEE Conference on Control Applications*, Hartford, Connecticut, October 1997.

Anders, Rantzer., and A. Megretski: "Hysteresis analysis based on integral quadratic constraints." In *Proceedings of European Control Conference*, Brussels, Belgium, 1997.

Andersson, Lennart, and Anders Rantzer: "Frequency dependent error bounds for uncertain linear models." In *Proceedings of the American Control Conference*, Albuquerque, New Mexico, 1997.

Årzén, Karl-Erik, and Charlotta Johnsson: "Grafchart: a Petri net/Grafcet based graphical language for real-time sequential control applications." In *SNART'97—The Swedish National Real-Time Systems Conference, Lund*, August 1997.

Åström, Karl Johan: "Limitations on control system performance." In *European Control Conference*, Brussels, Belgium, July 1997.

Åström, K. J., H. Panagopoulos, and T. Hägglund: "Design of PI controllers." In *Proc. 1997 IEEE International Conference on Control Applications*, pp. 417–422, Hartford, Connecticut, 1997.

Barabanov, A. E., A. Miroshnikov, and A. Rantzer: "Multiband *H*-infinity control in a behavioral setting." In *Proceedings of IEEE Conference of Decision and Control*, San Diego, California, 1997.

Barros, P. R., and B. Wittenmark: "Frequency domain sensitivity shaping using overparameterized controllers." In *Preprints 36th IEEE Conference on Decision and Control*, pp. 2716–2721, San Diego, California, December 1997.

Branicky, Michael S., and Sven Erik Mattsson: "Simulation of hybrid systems in Omola/OmSim." In Boullart *et al.*, Eds., *Computer Aided Control Systems Design, CACSD'97*, Gent, Belgium, April 1997. Pergamon.

Chou, C. T., M. Verhaegen, and R. Johansson: "Continuous-time identification of continuous-time systems." In *11th IFAC Symp. System Identification (SYSID'97)*, Kitakyushu, Fukuoka, Japan, July 1997.

Eborn, Jonas, and James Sørlie: "Parameter optimization of a nonlinear boiler model." In Sydow, Ed., *15th IMACS World Congress*, vol. 5, pp. 725–730, Berlin, Germany, August 1997. W & T Verlag.

Eker, Johan, and Anders Blomdell: "A structured interactive approach to embedded control." In *Preprints SNART '97, Lund, Sweden*, 1997.

Elmqvist, Hilding, and Sven Erik Mattsson: "An introduction to the physical modeling language Modelica." In Hahn and Lehmann, Eds., *Proceedings of the 1997 European Simulation Symposium (ESS'97)*, pp. 110–114, Passau, Germany, October 1997. SCS, The Society for Computer Simulation International.

Elmqvist, Hilding, and Sven Erik Mattsson: "Modelica—The next generation modeling language, an international effort." In *Proceedings of the 1st World Congress on System Simulation, WCSS'97*, Singapore, September 1997.

Gäfvert, Magnus: "Comparisons of two dynamic friction models." In *Proc. Sixth IEEE Conference on Control Applications (CCA)*, Hartford, Connecticut, October 1997.

Hägglund, Tore: "Stiction compensation in control valves." In *European Control Conference*, Brussels, Belgium, 1997.

Hägglund, Tore, and Karl Johan Åström: "Supervision of adaptive control algorithms." In *IFAC Conference on Control Applications*, Belfort, France, 1997.

Haverkamp, B. R. J., M. Verhaegen, C. T. Chou, and R. Johansson: "Continuous-time identification of MIMO state-space models from sampled data." In *11th IFAC Symp. System Identification (SYSID'97)*, Kitakyushu, Fukuoka, Japan, July 1997.

Johansson, K. H., A. Barabanov, and K. J. Åström: "Limit cycles with chattering in relay feedback systems." In *36th IEEE Conference on Decision and Control*, San Diego, California, 1997.

Johansson, Karl Henrik, and Anders Rantzer: "Multi-loop control of minimum phase processes." In *Proceedings of the American Control Conference*, Albuquerque, New Mexico, 1997.

Johansson, Mikael, Jörgen Malmborg, Anders Rantzer, Bo Bernhardsson, and Karl-Erik Årzén: "Modeling and control of fuzzy, heterogeneous and hybrid systems." In *Proceedings of 3rd IFAC Symposium*

on Intelligent Components and Instruments for Control Applications, SICICA, Annecy, France, 1997.

Johansson, Mikael, and Anders Rantzer: "Computation of piecewise quadratic Lyapunov functions for hybrid systems." In *Proceedings of the 1997 European Control Conference*, Brussels, Belgium, July 1997.

Johansson, Mikael, and Anders Rantzer: "On the computation of piecewise quadratic lyapunov functions." In *Proceedings of the 36th IEEE Conference on Decision and Control*, San Diego, California, December 1997.

Johansson, Rolf, Anders Robertsson, Klas Nilsson, and Michel Verhaegen: "State-space system identification of robot manipulator dynamics." In *Preprints SNART-97*, pp. 152–158, Lund, Sweden, August 1997.

Johansson, R., M. Verhaegen, and C. T. Chou: "Stochastic theory of continuous-time state-space identification." In *Proc. Conf. Decision and Control*, pp. 1866–1871, San Diego, California, December 1997.

Jönsson, Ulf: "A nonlinear popov criterion'." In *Proceedings of the 36th IEEE Conference on Decision and Control*, San Diego, California, 1997.

Jönsson, Ulf: "A popov criterion for systems with slowly time-varying parameters." In *Proceedings of the American Control Conference*, Albuquerque, New Mexico, 1997.

Malmborg, Jörgen, and Johan Eker: "Hybrid control of a double tank system." In *IEEE Conference on Control Applications*, Hartford, Connecticut, 1997.

Mattsson, Sven Erik: "On modeling of heat exchangers in Modelica." In Hahn and Lehmann, Eds., *Proceedings of the 1997 European Simulation Symposium (ESS'97)*, pp. 127–133, Passau, Germany, October 1997. SCS, The Society for Computer Simulation International.

Mattsson, Sven Erik, and Hilding Elmqvist: "Modelica—An international effort to design the next generation modeling language."

In Boullart *et al.*, Eds., *Computer Aided Control Systems Design, CACSD'97*, pp. 151–155, Gent, Belgium, April 1997. Pergamon.

Möllerstedt, Erik, Bo Bernhardsson, and Sven Erik Mattsson: "A simple model for harmonics in electrical distribution networks." In *Proceedings of the 36th IEEE Conference on Decision and Control*, San Diego, California, USA, December 1997.

Möllerstedt, Erik, Sven Erik Mattsson, and Bo Bernhardsson: "A new approach to steady-state analysis of power distribution networks." In Sydow, Ed., *15th IMACS World Congress*, vol. 5, pp. 677–682, Berlin, Germany, August 1997. W & T Verlag.

Nilsson, Johan, and Bo Bernhardsson: "LQG control over a Markov communication network." In *Proceedings of the 36th IEEE Conference on Decision and Control*, 1997.

Nilsson, Johan, Bo Bernhardsson, and Björn Wittenmark: "Timing problems in real-time systems." In *Proceedings of SNART 97, the Swedish Conference on Real-Time Systems*, pp. 112–115, 1997.

Öhman, Martin, Stefan Johansson, and Karl-Erik Årzén: "Implementation aspects of the PLC standard IEC 1131-3." In Boullart *et al.*, Eds., *Computer Aided Control Systems Design, CACSD'97*, pp. 27–32, Gent, Belgium, 1997. IFAC, Pergamon.

Overaa, Egil, Sven Erik Mattsson, and Anders Rantzer: "Robustness analysis of a wind power plant." In *Proceedings of European Control Conference*, Brussels, Belgium, July 1997.

Panagopoulos, Hélène, Karl Johan Åström, and Tore Hägglund: "A numerical method for design of PI controllers." In *IEEE Conference on control applications*, Hartford, Connecticut, 1997.

Panteley, E., R. Ortega, and M. Gäfvert: "An adaptive friction compensator for global tracking in robot manipulators." In *Proc. SYROCO '97, 5th IFAC Symposium on Robot Control*, Nantes, France, 1997.

Pedersen, Lars Malcolm, and Carsten Villadsen: "Control of a double side shear." In *Automation in the steel industri: Current Practice and Future Developments*. IFAC, 1997.

Rantzer, Anders, and Mikael Johansson: "Piecewise linear quadratic optimal control." In *Proceedings of the American Control Conference*, Albuquerque, New Mexico, June 1997.

Robertsson, Anders, and Rolf Johansson: "A note on 'nonlinear control using only position feedback: An observer backstepping approach'." In *Proceedings of Robotikdagarna 1997*, pp. 1–6, Linköping, Sweden, June 1997.

Simensen, Jo, Charlotta Johnsson, and Karl-Erik Årzén: "A multiple-view batch plant information model." In *Proceedings of PSE'97/ESCAPE-7*. Trondheim, Norway, 1997.

van der Geest, Robert, and Anders Rantzer: "Linear quadratic control under quadratic constraints." In *Proceedings of European Control Conference*, Brussels, Belgium, 1997.

Wallén, Anders: "Valve diagnostics and automatic tuning." In *Proceedings of the American Control Conference*, Albuquerque, New Mexico, 1997.

Conference Abstracts

Åkesson, Mats, Per Hagander, and Jan Peter Axelsson: "A pulse technique for control of fed-batch cultivations." In *Abstract book of 8th European Congress on Biotechnology*, Budapest, Hungary, August 1997.

Johansson, K. H., B. James, G. F. Bryant, and K. J. Åström: "Multivariable controller tuning—some preliminary results." In *Symposium on Quantitative Feedback Theory and Other Frequency-Based Methods and Applications*, University of Strathclyde, Glasgow, Scotland, 1997.

Johansson, Mikael: "System analysis using piecewise quadratic Lyapunov functions." In *Workshop on Multiple Model Approaches to Modelling and Control*, Trondheim, September 1997.

13. Reports

One PhD thesis and three Tech Lic theses have been published. The abstracts are presented in Chapter 8. Eighteen Master's theses have been completed and 18 internal reports.

Dissertations

Andersson, Lennart: *Comparison and Simplification of Uncertain Models*. Lic Tech thesis ISRN LUTFD2/TFRT--3216--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, January 1997.

Eker, Johan: *A Framework for Dynamically Configurable Embedded Controllers*. Lic Tech thesis ISRN LUTFD2/TFRT--3218--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 1997.

Johansson, Karl Henrik: *Relay Feedback and Multivariable Control*. PhD thesis ISRN LUTFD2/TFRT--1048--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1997.

Johnsson, Charlotta: *Recipe-Based Batch Control Using High-Level Grafchart*. Lic Tech thesis ISRN LUTFD2/TFRT--3217--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, June 1997.

Master Theses

Andreas, Helena: "Underwater locomotion of swimming cylinders." Master thesis ISRN LUTFD2/TFRT--5589--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 1997.

Areskoug, Thomas: "Identification of an excavator." Master thesis ISRN LUTFD2/TFRT--5579--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 1997.

Blomdell, Anders: "A real time control language for the Pålsjö environment." Master thesis ISRN LUTFD2/TFRT--5578--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 1997.

Brufani, Sabina: "Manual control of unstable systems." Master thesis ISRN LUTFD2/TFRT--5576--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 1997.

Bygren, Jonas: "Inverkningar av tidsfördröjning i samplade system," (Influence of time-delays in sampled-data systems). Master thesis ISRN LUTFD2/TFRT--5574--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, January 1997.

Danielsson, Mikael: "Control of an oscillatory systems." Master thesis ISRN LUTFD2/TFRT--5575--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 1997.

Hansson, Anders, and Per-Inge Tallberg: "Automatic tuning of a KaMeWa waterjet servo." Master thesis ISRN LUTFD2/TFRT--5582--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1997.

Hedlund, Sven: "Speech coding using orthonormal basis functions." Master thesis ISRN LUTFD2/TFRT--5572--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, January 1997.

Helander, Andreas: "Control design for a solvent extractor." Master thesis ISRN LUTFD2/TFRT--5587--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 1997.

Henriksson, Anders: "Java based picture editing and monitoring for power control systems." Master thesis 5573, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 1996.

Isaksson, Mats: "A comparison of some approaches to time-delay estimation." Master thesis ISRN LUTFD2/TFRT--5580--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, June 1997.

Lantz, Michael: "Robustness analysis using Omola with application to power networks." Master thesis ISRN LUTFD2/TFRT--5585--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, October 1997.

Löfgren, Ola, and Patrik Svensson: "Modelling and control of a plate heat exchanger in steam applications." Master thesis ISRN LUTFD2/TFRT--5584--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, October 1997.

Lopez, Pablo Tapia: "Automatic tuning based on transfer function estimation." Master thesis ISRN LUTFD2/TFRT--5583--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, August 1997.

Nockhammar, Ola: "An adaptive local model networks strategy for nonlinear control." Master thesis ISRN LUTFD2/TFRT--5581--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, June 1997.

Nordin, Oskar: "Förbättrad reglering av kvalitet på pappersmaskin," (Improved control of quality on a typical paper machine). Master thesis ISRN LUTFD2/TFRT--5586--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, October 1997.

Pettersson, Magnus: "Autofocus and control of a hematology instrument." Master thesis ISRN LUTFD2/TFRT--5591--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 1997.

Stojnic, Peter: "Modeling of steam generation in a sulphuric acid plant." Technical Report ISRN LUTFD2/TFRT--5577--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 1997.

Other Reports

Andreas, Helena: "Verification of anti-surge phenomena in axial flow compressor." Report ISRN LUTFD2/TFRT--7566--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1997.

Andreas, Helena, and Karl Johan Åström: "Design of PI controller by minimization of IAE." Report ISRN LUTFD2/TFRT--7565--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1997.

Dagnegård, Eva, and Tore Hägglund: "Activity report 1995–1996." Report ISRN LUTFD2/TFRT--4024--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, 1997.

Hägglund, Tore: "The idle index." Report ISRN LUTFD2/TFRT--7568--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, oct 1997.

Johansson, Karl Henrik, and Karl Johan Åström: "Projects in history of automatic control." Report ISRN LUTFD2/TFRT--7561--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, June 1997.

Johansson, Karl Henrik, and Anders Rantzer: "A convergence proof for relay feedback systems." Report ISRN LUTFD2/TFRT--7555--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, January 1997.

Jönsson, Ulf: "A Matlab toolbox for system analysis via integral quadratic constraints." Report ISRN LUTFD2/TFRT--7556--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, January 1997.

Möllerstedt, Erik, Sven Erik Mattsson, and Bo Bernhardsson: "Modeling of electricity distribution networks and components. Status report for Elforsk project 3153." Report ISRN LUTFD2/TFRT--7557--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 1997.

Nilsson, Bernt: "Processreglering – Föreläsningsanteckningar 97," (Process control—Lecture notes 97). Report ISRN LUTFD2/TFRT--7560--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, June 1997.

Panagopoulos, Hélène, Tore Hägglund, and Karl Johan Åström: "The Lambda method for tuning PI controllers." Report ISRN LUTFD2/TFRT--7564--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, August 1997.

Rantzer, Anders, and Alexander Megretski: "System analysis via integral quadratic constraints. part ii." Report ISRN LUTFD2/TFRT--7559--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1997.

Reports Available

Only a limited number of copies of our reports are available for sale from the Department. Any of the listed publications may, however, be borrowed through your library service or from the following libraries in Sweden:

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- UB 2, Svenska Tryckavdelningen, Box 1010, S-221 03 Lund
- Stockholms Universitetsbibliotek, Svenska Tryckavdelningen, S-106 91 Stockholm
- Kungliga Biblioteket, Box 5039, S-102 41 Stockholm
- Umeå Universitetsbibliotek, Box 718, S-901 10 Umeå
- Uppsala Universitetsbibliotek, Box 510, S-751 20 Uppsala

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14. Lectures by the Staff outside the Department

Seminars and lectures given by the staff outside the department. The persons are listed alphabetically.

Åkesson, Mats

A Pulse Technique for Control of Fed-batch Fermentations, 1997 IEEE Conference on Control Applications, Hartford, Connecticut, USA, October 6, 1997.

A Pulse Technique for Control of Fed-batch Fermentations, McMaster Control Consortium, McMaster University, Hamilton, Ontario, Canada, October 16, 1997.

Integrated Control and Fault Detection for a Mechanical Servo Process, IFAC Symposium on Fault Detection, Supervision and Safety for Technical Processes, Hull, UK, August 28, 1997.

Bioprocess Control, Graduate course, Department of Physics and Measurement Technology, Linköping University, Sweden, June 12, 1997.

Beyond First Order Kinetics, Graduate course, Department of Radiation Physics, University Hospital MAS, Malmö, Sweden, February 27, 1997.

Andersson, Lennart

Frequency Dependent Error Bounds for Uncertain Linear Models, American Control Conference, Albuquerque, New Mexico, June 4, 1997.

Årzén, Karl-Erik

High-Level Grafcet for Supervisory Sequential Control, Software Engineering Institute, Carnegie Mellon University, Pittsburgh Pennsylvania, March 14, 1997.

High-Level Grafcet for Supervisory Sequential Control, Gensym Corp, Cambridge, Massachusetts, March 17, 1997.

Fuzzy Control—A Nonlinear Perspective, ITM Annual Meeting, Göteborg, Sweden, April 14, 1997.

Modeling and Control of Fuzzy, Heterogeneous and Hybrid Systems, IFAC SICICA Symposium, Annecy, France, June 9, 1997.

Grafchart: A Petri Net/Grafcet Based Graphical Language for Real-Time Sequential Control Applications, SNART 97 conference, Lund, Sweden, August 21, 1997.

Grafchart: A Graphical Language for Supervisory Sequential Control, Gensym Nordic Users Meeting, Kista, Sweden, September 23, 1997.

S88 Recipes and Object-Oriented SFC, Pharmacia-Upjohn, Strängnäs, Sweden, October 21, 1997.

Grafchart and Recipe-Based Batch Control, Department of Engineering Cybernetics (ITK), Norwegian University of Science and Technology (NTNU), Trondheim, Norway, November 14, 1997.

Åström, Karl Johan

Adventures in Process Control: From System Identification to Automatic Tuning, Invited plenary lecture 7th Nordic Process Control Workshop, Wadahl, Norway, January 13, 1997.

A Nonlinear Observer for the Inverted Pendulum, COSY Workshop on Control of Nonlinear and Uncertain Systems, European Science Foundation, ETH, Zürich, Switzerland, January 18, 1997.

Friction Modeling and Friction Compensation, California Institute of Technology, California, March 19, 1997.

Control of Hybrid Systems, California Institute of Technology, California, March 20, 1997.

Modeling and Simulation of Dynamical Systems, California Institute of Technology, California, March 21, 1997.

Limitations on Control System Performance, European Control Conference, Brussels, Belgium, July 1, 1997.

Modeling of Physical Systems, COSY Workshop on Control of Comples Systems, European Science Foundation, Computer and Automation Research Institute, Hungarian Academy of Sciences Budapest, Hungary, October 12, 1997.

Automatic Tuning, Adaptation and Autonomous Control, New trends in systems and control. Sevilla, Spain, November 19, 1997.

Advances in Process Control—A Key to Improved Quality and Productivty, Invited lecture, ASTRA, Södertälje, Sweden, September 1997.

PID Control, Invited lecture, ABB, Ludvika, Sweden, September 16, 1997.

Introduction of Integral Action in State Feedback, Department of Systems Engineering, Universidad Polite'cnia de Valencia, Spain, November 11, 1997.

Fundamental Limitations on Control System Performance, Department of Systems Engineering, Universidad Polite'cnia de Valencia, Spain, November 14, 1997.

Tools for Modeling Physical Systems, Invited lecture Workshop on Theoretical Foundations of Virtual Engineering and Complex Systems, California Institute of Technology, California, December 3, 1997.

Modeling and Control of Systems with Friction, Invited lecture Workshop on Theoretical Foundations of Virtual Engineering and Complex Systems, California Institute of Technology, California, December 3, 1997.

Manual Control of an Unstable System with Saturating Actuator, IEEE Conference on Decision and Control, San Diego, California, December 10, 1997.

Bernhardsson, Bo

LQG Control Over a Markov Communication Network, CDC, San Diego, California, December 12, 1997.

Real Perturbation Values, Invited lecture. UCSD, San Diego, California, December 15, 1997.

Computation of the Real Stability Radius and the Real Perturbation Values, University of California, San Diego, California, December 15, 1997.

Eborn, Jonas

Parameter Optimization of a Non-linear Boiler Model, 15th IMACS World Congress, Berlin, Germany, August 28, 1997.

Modellering och Reglering av Energiprocesser, Sydkraft Forskningsstiftelsedag, Malmö, Sweden, September 4, 1997.

Eker, Johan

A Structured Interactive Approach to Embedded Control, Invited lecture, Lund-Lyngbydagen, Lund, Sweden, November 14, 1997.

Gäfvert, Magnus

Comparisons of Two Dynamic Friction Models, Sixth IEEE Conference on Control Applications (CCA), Hartford, Connecticut, October 6, 1997.

Hagander, Per

Bioprocess Control, Graduate course, Department of Physics and Measurement Technology, Linköping University, Sweden, June 12, 1997.

Hägglund, Tore

Control Strategies Applied in Process Control, Workshop arranged by Alfa Laval AS, Oslo, Norway, April 24, 1997.

Supervision of Adaptive Control Algorithms, IFAC Conference on control applications, Belfort, France, May 21, 1997.

Stiction Compensation in Control Valves, European Control Conference, Brussels, Belgium, July 3, 1997.

PID Control and Automatic tuning, ABB Power Systems, Ludvika, Sweden, September 16, 1997.

Detection and Compensation for Friction in Control Valves, Åbo Akademi University, Turku, Finland, October 17, 1997.

PID Control and Automatic Tuning, Danfoss, Sönderborg, Denmark, November 21, 1997.

Johansson, Karl Henrik

Multi-Loop Control and Relay Feedback, Control Systems Centre, UMIST, Manchester, UK, January 21, 1997.

Multi-Loop Control of Minimum Phase Processes, 16th American Control Conference, Albuquerque, New Mexico, June 6, 1997.

Multivariable Controller Tuning—Some Preliminary Results, Symposium on Quantitative Feedback Theory and Other Frequency-Based Methods and Applications, Glasgow, Scotland, August 22, 1997.

Limit Cycles with Chattering in Relay Feedback Systems, 36th IEEE Conference on Decision and Control, San Diego, California, December 11, 1997.

Fast Switches in Relay Feedback Systems, Information Systems Lab, Stanford, California, December 16, 1997.

Johansson, Mikael

On the Computation of Piecewise Quadratic Lyapunov Functions, 36th IEEE Conference on Decision and Control, San Diego, December 1997.

Piecewise Linear Quadratic Optimal Control, American Control Conference, Albuquerque, June 1997.

Computation of Piecewise Quadratic Lyapunov Functions for Hybrid Systems, European Control Conference, Brussels, Belgium, July 1997.

Stability Analysis of Piecewise Affine Systems, Ensta, Paris, January 1997.

Johansson, Rolf

Nonlinear Velocity Observers, Control and Dynamical Systems California Institute of Technology, Pasadena, California, June 23, 1997.

System Identification of Atrial Activation during Chronic Atrial Fibrillation in Man, IEEE Conf. Computers in Cardiology, Lund, Sweden, September 9, 1997.

Stochastic Theory of Continuous-Time State-Space Identification, IEEE Conf. Decision and Control (CDC'97) San Diego, California, December 11, 1997.

Johnsson, Charlotta

High-Level Grafcet for Supervisory Sequential Control, Nutek Regina Conference, Stockholm, Sweden, January 20–21, 1997.

High-Level Grafcet for Supervisory Sequential Control, Guest lecture. ENSIEG, Grenoble, France, March 13, 1997.

High-Level Grafchart for Representation of Batch Recipes and Batch Plants, European Batch Forum Meeting, Malmö, Sweden, November 17, 1997.

Malmborg, Jörgen

Heterogeneous Control of HVAC Systems, NUTEK REGINA-Program, Täby, Sweden, January 20–21, 1997.

Simulation and Analysis of Hybrid Systems, Lecture in the PhD course on hybrid control systems, Lund, Sweden, February 13, 1997.

Hybrid Control of a Double Tank System, The CCA conference in Hartford, Connecticut, October 5, 1997.

Mattsson, Sven Erik

Modeling and Simulation of Relay-like Systems, Docent lecture, Lund Institute of Technology, February 21, 1997.

Modelica and Activities in Lund, NUTEK Workshop Needs and Visions in Modeling and Simulation, NUTEK research program Complex technical systems, Stockholm, Sweden, April 22, 1997.

Simulation of Hybrid Systems in Omola/OmSim, the 7th IFAC Symposium on Computer Aided Control Systems Design (CACSD'97), Gent, Belgium, April 28, 1997.

Modelica—An international effort to design the next generation modeling language, the 7th IFAC Symposium on Computer Aided Control Systems Design (CACSD'97), Gent, Belgium, April 28, 1997.

Modelica—An International Effort to Design the Next Generation Modeling Language, COSY workshop "Mathematical Modelling of complex Systems," European Science Foundation, Groningen, The Netherlands, August 29–30, 1997.

Activities in the Project "Modelling and Control of Energy Processes", Sydkraft AB, Malmö, Sweden, September 4, 1997.

Modelling and Simulation of Electric Power Systems—Examples from Using Omola and OmSim, Elforsk seminar "Object-oriented modeling and simulation for power Processes," Stockholm, September 23, 1997.

Modeling and Simulation of Relay-like Systems, Docent lecture, Lund Institute of Technology, February 21, 1997.

Modelica—A Key to Complex Systems, Information day, NUTEK research program "Complex technical systems," NUTEK, Stockholm, October 2, 1997.

On Modeling of Heat Exchangers in Modelica, the 1997 European Simulation Symposium (ESS'97), Passau, Germany, October 20, 1997.

Möllerstedt, Erik

Harmonic Modeling of Loads in Power Distribution Networks, Invited lecture, Lund-Lyngbydagen, Lund, Sweden, May 15, 1997.

A New Approach to Steady-State Analysis of Power Distribution Networks, 15th IMACS World Congress, Berlin, Germany, August 25, 1997.

A Simple Model for Harmonics in Electrical Distribution Networks, 36th IEEE Conference on Decision and Control, San Diego, California. Dec 11, 1997.

Nilsson, Johan

Timing Problems in Real-Time Systems, SNART 97, the Swedish Conference on Real-Time Systems, Lund, Sweden, August 24, 1997.

Öhman, Martin

Implementation Aspects of the PLC Standard IEC 1131-3, Conference CACSD-97. Gent, Belgium, April 28, 1997.

Panagopoulos, Hélène

Design of PI Controllers, Plenary lecture. Sheraton Hartford Hotel, Hartford, Connecticut, October 6, 1997.

Pedersen, Lars Malcolm

Automation in the Steel Industri: Current Practice and Future Development, IFAC Work Shop, Kyunghoo, Korea, July 16, 1997.

Reheat Furnace Control, Lund-Lyngby Day, Lyngby, Denmark, November 14, 1997. november 14th.

Rantzer, Anders

Computation of Piecewise Quadratic Lyapunov Functions, ETH, Zürich, Schweiz, January 17, 1997.

System Analysis via Integral Quadratic Constraints, Laboratoire d'Automatique de Grenoble, France, March 17, 1997

Performance Limitations in Multi-variable Control, NTH, Trondheim, Norway, May 5, 1997.

Piecewise Linear Quadratic Control, MIT, Boston, Massachusetts, May 27, 1997.

Rate Limiters and Multiple Equilibria via Integral Quadratic Constraints, Caltech, Pasadena, June 10, 1997.

Piecewise Linear Quadratic Control, Caltech, Pasadena, June 12, 1997.

Rate Limiters and Multiple Equilibria via Integral Quadratic Constraints, University of California at Santa Barbara, June 16, 1997.

Piecewise Linear Quadratic Control, University of California at Santa Barbara, June 18, 1997.

Rate Limiters and Multiple Equilibria via Integral Quadratic Constraints, University of Minnesota, Minneapolis, June 24, 1997.

Piecewise Linear Quadratic Control, University of Minnesota, Minneapolis, June 26, 1997.

Hysteresis Analysis Based on Integral Quadratic Constraints, European Control Conference, Brussels, July 3, 1997.

Time and Frequency Domain Analysis of Nonlinear and Uncertain Systems, COSY Workshop, Budapest, October 11, 1997.

Robustness Analysis with Application to Power Networks, VECS Workshop, Caltech, Pasadena, December 2, 1997.

Multiband H-infinity Control in a Behavioral Setting, IEEE CDC Conference, San Diego, December 11, 1997.

Robertsson, Anders

A note on 'Nonlinear Control Using Only Position Feedback: An Observer Backstepping Approach', Robotikdagarna 1997, Linköping, Sweden, June 10, 1997.

State-Space System Identification of Robot Manipulator Dynamics, Poster presentation at SNART 97, Lund, Sweden, August 22, 1997.

Wallén, Anders

Valve Diagnostics and Automatic Tuning, American Control Conference. Albuquerque, New Mexico, June 6, 1997.

Structuring Control Algorithms With Grafcet, Danfoss Drives, Graasten, Denmark, November 21, 1997.

Wittenmark, Björn

Virtual Interactive Systems, Dynamic Pictures and Control Education,, Invited lecture, Matlab Nordic Tour, Stockholm, Sweden April 21, 1997.

Virtual Interactive Systems, Dynamic Pictures and Control Education,, Invited lecture, Matlab Nordic Tour, Lund, Sweden, April 22, 1997.

Virtual Interactive Systems, Dynamic Pictures and Control Education,, Invited lecture, Matlab Nordic Tour, Helsinki, Finland, April 25, 1997.

Adaptive Extremal Control,, Invited lecture, University of British Columbia, Vancouver, Canada, May 23, 1997.

A Survey of Adaptive Control Applications,, Invited plenary talk, DMCA '97 Workshop, Dynamic Modeling Control Applications for Industry, Vancouver, Canada, May 26, 1997.

Interactive Use of Matlab in Control Education,, Invited plenary talk, Matlab Nordic Conference, Stockholm, Sweden October 27, 1997.

15. Seminars at the Department

Seminars presented in order of date. The seminars were given at the department during 1997, both by the staff and by invited lecturers. Disserterations and master theses presentations are also included.

AC = Department of Automatic Control, Lund Institute of Technology
LTH = Lund Institute of Technology

Andrey Barabanov (St. Petersburg University): *Design of L1- and Hinf-regulators—a survey.* January 16, 1997.

Bernardo A. León de la Barra S. (Universidad de Chile): *Frequency Domain Properties of Discrete Time Zeros.* January 23, 1997.

Lennart Andersson (LTH): *Comparison and Simplification of Uncertain Models.* January 28, 1997. Lic Tech dissertation seminar.

Mikael Danielsson (LTH): *Control of an Oscillatory System.* January 30, 1997. MSc-thesis presentation.

Sven Hedlund (LTH): *Speech Coding using Orthonormal Basis Functions.* February 13, 1997. MSc-thesis presentation.

Jonas Bygren (LTH): *Compensation for Jitter in Real-time Systems.* February 13, 1997. MSc-thesis presentation.

Sabina Brufani (University of Rome): *Manual Control of Unstable Systems.* February 19, 1997. MSc-thesis presentation.

Robert van der Geest (University of Twente): *The Kalman-Yakubovich-Popov Lemma in a Behavioural Framework.* February 20, 1997.

Sven Erik Mattsson (LTH): *Modeling and Simulation of Relay-like Behaviors.* February 21, 1997. Docent lecture.

Peter Stojnic (LTH): *Modelling of Steam Generation in a Sulphuric Acid Plant.* February 26, 1997. MSc-thesis presentation.

Fredrik Gustafsson (Linköping University): *Fault Detection with Car Applications.* February 27, 1997.

Pericles R. Barros (Universidade Federal da Paraiba, Brazil): *Frequency Domain Sensitivity Shaping Using Overparametrized Controllers.* February 27, 1997.

Karl-Erik Årzén, Charlotta Johnsson (AC): *High-level Grafcet for Supervisory Sequential Control.* March 4, 1997.

Manfred Morari (ETH): *Model Predictive Control—Recent Results and Research Issues.* March 6, 1997.

Bruce H. Krogh (Carnegie-Mellon University): *Generating Approximating Automata for Hybrid Systems for Verification and Controller Synthesis.* March 24, 1997.

Andrey Barabanov (St. Petersburg University): *Multiband H_∞ Control in a Behavioural Setting.* March 26, 1997.

Sven Khatri (California Institute of Technology): *Virtual Engineering.* April 2, 1997.

rik Möllerstedt (AC): *Modeling of Loads in Electric Power Distribution Networks for Harmonic Distortion Analysis.* April 8, 1997.

Romeo Ortega (CNRS-SUPELEC, France): *Passivity-Based Control of Euler-Lagrange Systems.* April 9, 1997.

Romeo Ortega (CNRS-SUPELEC, France): *An Adaptive Notch Filter with Guaranteed Stability Properties.* April 11, 1997.

Hassane Alla (ENSIEG, France): *The Supervised Control of Discrete Dynamic Systems.* April 24, 1997.

Leif Andersson (AC): *Video Presentations in LaTeX—New Possibilities with Postscript Pictures.* May 14, 1997.

Thomas Areskoug (LTH): *Identification of an Excavator.* May 21, 1997. MSc-thesis presentation.

Ola Nockhammar (LTH): *An Adaptive Local Model Networks Control Strategy.* May 23, 1997. MSc-thesis presentation.

Mats Isaksson (LTH): *A comparison of some Approaches to Time Delay Estimation.* May 30, 1997. MSc-thesis presentation.

Karlene A. Kosanovich (Univ. of Southern Carolina): *Transition Control For Time-Delay Systems.* May 30, 1997.

George Wang (NRC, Canada): *New Estimation and Control Techniques for Industrial Control Systems.* June 2, 1997.

Sylvain Gendron (Paprican, Canada): *Model Weighting Adaptive Control: Theory and Applications.* June 3, 1997.

Charlotta Johnsson (AC): *Recipe-based Batch Control using High-level Grafchart.* June 6, 1997. Lic Tech dissertation seminar.

Richard M. Murray (CalTech): *Modeling and Nonlinear Control of Axial Flow Compressors.* June 26, 1997.

Luis Rocha Nunes (LTH): *Modeling and Control of the Quad-Tank Process.* August 6, 1997. MSc-thesis presentation.

Pablo Tapia Lopez (LTH): *Automatic Tuning based on Transfer Function Estimation.* August 12, 1997. MSc-thesis presentation.

Jan Sternby (AC): *Hough Transformation for Curve Fitting.* September 2, 1997.

Anders Hansson, Per-Inge Tallberg (LTH): *Automatic Tuning of Controller for KaMeWa WaterJetServo.* September 8, 1997. MSc-thesis presentation.

Mohammed M'Saad (ISMRA, Caen, France): *Adaptive Control in Presence of Input Constraints—An Input-Output Approach.* September 8, 1997.

Paolo Tona, Joël Chebassier, Mohammed M'Saad (Grenoble and Caen, France): *SIMART: A Learning Basis for Adanved Control Techniques.* September 9, 1997.

Joël Chebassier (LAG, Grenoble, France): *Closed Loop Identification.* September 9, 1997.

Jonas Eborn (AC): *Models of Heat Exchangers in K2.* September 11, 1997.

Mikael Johansson (AC): *Linear Matrix Inequalities in Control.* September 1997.

Per Brath (Aalborg University, Denmark): *Presentation of Danfoss, Aalborg University, and my licentiate thesis.* September 15, 1997.

Jan Komorowski (Norwegian University of Science and Technology,Trondheim): *Adaptive Decision Support—The Rough Set Approach.* September 29, 1997.

Mats Åkesson (AC): *A Pulse Technique for Control of Fed-batch Fermentations.* October 2, 1997.

Ola Löfgren och Patrik Svensson (LTH): *Modelling and Control of a Plate Heat Exchanger in Steam Applications.* October 16, 1997. MSc-thesis presentation.

Oskar Nordin (LTH): *Control of Quality on a Paper Machine.* October 16, 1997. MSc-thesis presentation.

Anders Hansson (Information Systems Laboratory, Stanford University): *Robust Optimal Control of Linear Discrete Time Systems using Primal-Dual Interior-Point Methods.* October 20, 1997.

Andreas Helander (LTH): *Robustness Analysis using Omola with Application to Power Networks.* October 27, 1997. MSc-thesis presentation.

Michael Lantz (LTH): *Robustness Analysis using Omola with Application to Power Networks.* October 27, 1997. MSc-thesis presentation.

Willi Kortüm (DLR, Inst. for Robotics and System Dynamics): *Mechatronics in Ground Transportation.* October 31, 1997.

Johan Eker (AC): *A Framework for Dynamically Configurable Embedded Controllers.* November 12, 1997. Lic Tech dissertation seminar.

Dag Folkesson (Saab AB): *Principles for Real-Time Execution in some Swedish Avionics Systems.* (Part of the course Real-Time Systems.) November 12, 1997.

Brett Ninness (University of Newcastle, Australia): *Orthonormal Bases for System Identification: Useful or not?.* November 21, 1997.

Hendrik Nijmeijer (University of Twente): *Synchronization of Oscillators.* November 24, 1997.

Hendrik Nijmeijer (University of Twente) and **Karl Henrik Johansson** (AC): Doctoral Dissertation defence of the thesis *Relay Feedback and Multivariable Control.* November 25, 1997.

Fredrik Emilsson (LTH): *Control of the Ball on the Beam Process Using a Video Camera.* November 25, 1997. MSc-thesis presentation.

Magnus Pettersson (LTH): *Autofocus Control.* December 19, 1997. MSc-thesis presentation.