Activity Report: Automatic Control 1999

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Activity Report

Automatic Control

1999

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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, 1999.

The budget for 1999 was 24.5 MSEK, which is a slight increase compared to last year. The proportion coming from the University was 42%.

Seven PhD theses were defended this year, by Charlotta Johnsson, Mikael Johansson, Lars Malcolm Pedersen, Lennart Andersson, Johan Eker, Anders Robertsson and Mats Åkesson. This brings the total number of PhDs graduating from our department to 57. A Lic Tech thesis was completed by Sven Hedlund. Five new PhD students have been admitted during the year: Johan Bengtsson, Lena de Maré, Bo Lincoln, Rasmus Olsson and Stefan Solyom.

In the civilingenjör (master) program we have eight courses. The total number of students that finished the courses was 686, and 30 students completed their master theses. The total teaching effort corresponds to about 100 full-year equivalents.

Research at the department is presented under the following headlines: nonlinear and uncertain systems, modeling and simulation, process control, robotics and applications.

Some members of the department have received honors and awards, see Chapter 9. For instance, Karl Johan Åström was given the King's Medal of the 8th dimension with the ribbon of the order of the Seraphim.

Anders Rantzer was appointed professor at the department from July 1, 1999. As a consequence of a change in the promotion system at Swedish universities Bo Bernhardsson, Per Hagander, Tore Hägglund, and Rolf Johansson have been promoted to professors in automatic control at the department during 1999. The promotions are a recognition of the good research done at the department and we now are in an even stronger position with respect to academic staff and possibilities for research.

A highlight of the year was the Åström Symposium on August 28, which was organized in honor of Karl Johan Åström who retired from his professor position by the end of 1999. The symposium had ten specially invited speakers with outstanding international reputation and more than 200 participants.

Our retrospect this year, Chapter 7, describes our research interaction with neuroscience since the early 1970s. In particular, this concerns applications of system identification and control in the understanding of human neurophysiology of balance.

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

	94/95	95-96	97	98	99	Sum
Books	2	1	2	1	0	6
Papers	17	30	15	24	24	110
Conference papers	24	71	45	37	45	222
PhD theses	3	3	1	2	7	16
Licentiate theses	0	2	3	6	1	12
Master theses	23	40	18	20	25	126
Internal reports	15	18	11	11	8	63

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), Active Biotech, Lund Research Center AB, Elforsk, the European Council, Foundation for Strategic Research (SSF), Pharmacia & Upjohn, Sydkraft AB, Tetra Pak Research & Development AB, and Volvo Techical Development AB 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.

During the year our web has been accessed from far more than 15,000 sites all over the world.

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:

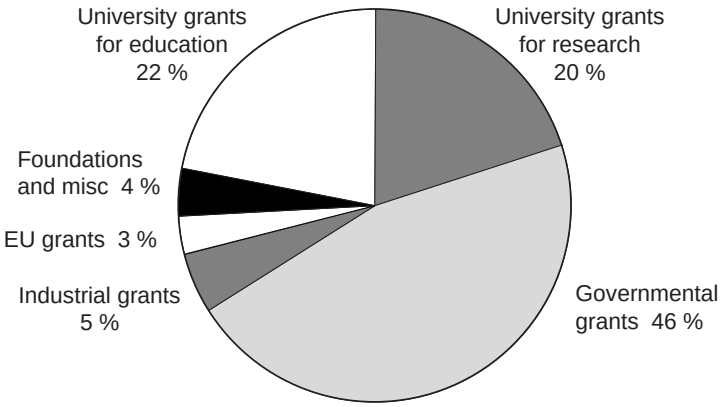
```
ftp://ftp.control.lth.se/pub
```

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.

3. Economy and Facilities

The turnover for 1999 was 24.5 MSEK, the same as last year. The income comes from Lund University (42%) and from external grants; the distribution is shown below.



Funding

Lund University provides partial support for graduate students. The majority of our research is, however, externally funded from governmental agencies and industry. During 1999 we had the following contracts:

- TFR – Block grant
- NUTEK – Modelling and Simulation of Complex Systems
- NUTEK – Lund Research Programme in Autonomous Robotics
- NUTEK – Data Integration and Force Control for Robots
- NUTEK – Automatic Control and Driver Model

- NUTEK – Motion Control
- NUTEK – Process Control for Cultivation of Micro Organisms
- NUTEK – Real-Time Systems
- NUTEK – Distributed Control of Safety Critical Systems
- NUTEK – Basic Control Functions for the Process Industry
- NUTEK – Lund Center for Applied Software Research (LUCAS)
- STINT – Funding for research collaboration with Caltech
- SSF – Center for Chemical Process Design and Control (CPDC)
- SSF – Computational Analysis of Dynamical Models
- SSF ARTES – Integrated Control of Scheduling
- ELFORSK – Modeling of Electric Power Networks
- Sydkraft – Modeling and Control of Energy Processes
- Pharmacia&Upjohn – Control of Genetically engineered *E. coli*.
- EU ESPRIT LTR – Fuzzy Algorithms for MIMO Control
- EU ESPRIT LTR – Heterogeneous Hybrid Control (H2C)

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 on their desks workstations connected to this network. For all academic staff the machines are SparcStation Ultra1 or better. There is also a powerful central computer for heavy computations.

Teaching Laboratory

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. There are almost 600 students, and on the average they spend about 20 hours each in the lab.

The transition from WindowsNT to Linux in the lab is almost done. It must be described as a complete success, with a considerable increase in flexibility and performance. It has also resulted in much less work for the computer maintenance staff. The Linux configuration is: Red Hat 6.x, UTIME kernel timer resolution patch, COMEDI control and measurement device interface (`http://hegel.ittc.ukans.edu/projects/utime` and `http://stm.lbl.gov/comedi`).

Robotics Laboratory

A thorough reconstruction of the Robotics Laboratory was made during 1999. The robot hardware including an ABB Irb-6 and and Irb-2000 were integrated into a new laboratory space with new equipment to facilitate security and ergonomics. Signal processing was improved by means of new PowerPCs and new force sensors (JR3). Beside the security equipment (Jokab), new computers (Sun Ultra 60, PC) were added to the previous range of SGI and Sun computers.

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). Our courses are listed in Table 4.1.

During 1999, 686 students passed our courses and 30 students completed their master-thesis projects. The number of registered students corresponded to 97 full-year equivalents during the year.

Topics for the master theses were in the following areas: Control of nonlinear and uncertain systems (6), Modeling and simulation (4), Signal processing (5), Real-time systems (1), Robotics (1), Automotive applications (4), Process control (3). A list of the master theses is given in Chapter 13.

Information on WWW

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, lecture notes, documentation, manuals, old exams, etc.

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

You find the education links at `http://www.control.lth.se/education/`.

Table 4.1 Courses and the number of students that passed.

Reglerteknik AK–FED *FRT010* (Automatic Control, basic course)	321
Reglerteknik AK–M *FRT060* (Automatic Control, basic course)	125
Processreglering (K) *FRT080* (Automatic Process Control)	30
Digital Reglering (FED) *FRT020* (Computer-Controlled Systems)	57
Realtidssystem (FED) *FRT031* (Real-Time Systems)	76
Systemidentifiering (FED) *FRT041* (System Identification)	24
Adaptiv reglering (FED) *FRT050* (Adaptive Control)	24
Olinjär reglering och Servosystem (M) *FRT075* (Nonlinear Control and Servo Systems)	19
Projekt i reglerteknik *FRT090* (Project in Automatic Control)	5
Internationell projektkurs i reglerteknik *FRT100* (International Project Course in Automatic Control)	5
Examensarbete 20 poäng *FRT820* (Master-thesis project, 4 months)	30

Doctorate Program

Seven PhD theses were defended by Charlotta Johnsson, Mikael Johansson, Lars Malcolm Pedersen, Lennart Andersson, Johan Eker, Anders Robertsson, and Mats Åkesson. This brings the total number of PhDs graduating from our department to 57. A Lic Tech thesis was completed by Sven Hedlund. Abstracts of the theses are given in Chapter 8.

We have admitted five new PhD students during the year: Johan Bengtsson, Lena de Maré, Bo Lincoln, Rasmus Olsson and Stefan Solyom.

The following PhD courses were given:

- Linear Systems I (A. Rantzer) 5 points
- Convex optimization (S. Boyd and A. Rantzer) 3 points
- Optimal control (A. Rantzer) 5 points
- Linear Quadratic Control (A. Ghulchak) 5 points
- Game Theory (B. Bernhardsson) 4 points
- Tools for control (B. Bernhardsson) 3 points
- Process Control (B. Wittenmark) 2 points
  (within the CPDC Graduate School)
- Model Predictive Control (J. Maciejowski) 3 points

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 covers both theory and applications.

The major research areas are:

- Nonlinear and Uncertain Systems
- Modeling and Simulation
- Process Control
- Robotics
- 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.

Nonlinear and Uncertain Systems

Control of Uncertain Systems

Researchers: Anders Rantzer, Bo Bernhardsson, Andrey Ghulchak, Lennart Andersson

Current developments in control theory are closely linked to the rapid improvements of computer tools for design, analysis, and simulation. The aim of this project is to pursue this combined development of theoretical and computational tools, and define new directions motivated by industrial problems. Our main investigations deal with stability and performance analysis for systems with uncertainty as well as controller optimization.

For several years, we have been developing the analysis framework based on integral quadratic constraints. This work is done in cooperation with prof. A. Megretski at MIT. The activity has resulted in sequence of joint publications and a Matlab toolbox named IQCbeta (See `http://www.control.lth.se/~rantzer/IQCbeta.html`) to support the analysis of interconnected systems.

Some good benchmark examples from power technology have motivated us to study stability robustness of differential-algebraic systems. The effects of parametric uncertainty, such as load variations in the power networks, are hard to analyze, both because of the system size and because the equilibrium point varies with the parameters. To handle variations in the equilibrium point is an important problem for nonlinear systems and approach it using a variant of so called μ-analysis.

Andrey Ghulchak works as guest researcher and together with Anders Rantzer he studies optimization with frequency domain constraints. This problem area has a wide variety of applications in control and the initial investigations have been focused on a convex parameterization of controllers that achieve robustness with respect to parametric uncertainty.

Hybrid Control

Researchers: Karl Johan Åström, Bo Bernhardsson, Sven Hedlund, Mikael Johansson, Stefan Solyom and Anders Rantzer

Hybrid systems is an active research area on the border between Computer Science and Automatic Control. One 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.

In this project, a computational approach to hybrid systems has been developed by within the thesis by Mikael Johansson. The work is directed towards stability and performance analysis for piecewise linear

systems. Piecewise quadratic Lyapunov functions and cost functions are computed by convex optimization. The method is a generalization of earlier work on quadratic stability and gives big flexibility for analysis of hybrid systems.

The department is one of four partners in the ESPRIT-project "Heterogeneous Hybrid Control". Within this project, a hybrid optimal control problem has been stated and solved computationally using linear programming.

Analysis of Electric Power Quality in Distribution Networks and Loads

Researchers: Bo Bernhardsson, Erik Möllerstedt and Anders Rantzer

Power quality is crucial for many consumers of electricity as well as for network owners. Nonlinear and switching loads are sources of disturbances, such as harmonics, that are extremely complicated to analyze and simulate in large networks. The aim of the project is to derive simple representations for networks with nonlinear and switching components. These should describe the behaviour of the networks close to nominal operating conditions, and simplify analysis and simulation. Of special interest is the amount of harmonic distortion. For switching components, there is coupling between different frequencies, which means that energy can be transfered from one frequency to another. This means that traditional linear analysis does not apply.

A standard method to predict e.g. instability risks is to compute impedance functions between relevant points, i.e. calculating impedances as functions of frequency. This is a linear method, which implicitly assumes that there are no couplings between different frequencies. This is not true for nonlinear networks. More accurate results can be obtained by considering the interconnections between different frequencies introduced by nonlinear loads.

In the licentiate work, Möllerstedt studied a model structure for steady state analysis called *Harmonic Norton Equivalents* (HNEs). Like the well known Norton Equivalent for linear networks, the HNE equivalently describes the behaviour of a whole network, and can be obtained experimentally. The HNE is a linearization of the system

around the nominal trajectory (such as a sinusoidal voltage), which results in a linear time periodic (LTP) system.

During 1999 the work has followed two main lines: The first is development of *frequency domain methods for analysis of LTP systems*. This is based on the harmonic transfer function which is an infinite-dimensional matrix, $H(s)$, that relates the input and output spectra. If

$$\begin{aligned} u(t) &= e^{st}\sum_m U_m e^{jm\omega_0 t} \\ y(t) &= e^{st}\sum_n Y_n e^{jn\omega_0 t} \end{aligned}$$

and this is represented by the infinite vectors

$$\begin{aligned} U(s) &= \begin{bmatrix} \dots & U_{-1} & U_0 & U_1 & \dots \end{bmatrix}^T e^{st}, \\ Y(s) &= \begin{bmatrix} \dots & Y_{-1} & Y_0 & Y_1 & \dots \end{bmatrix}^T e^{st}, \end{aligned}$$

then a linear time periodic system can be written as

$$Y(s) = H(s)U(s).$$

The transfer function matrix $H(s)$ defines the coupling between different frequencies and is called the harmonic transfer function (HTF) and can, formally, be represented as a doubly-infinite matrix.

$$H(s) = \begin{bmatrix} \ddots & \cdots & \cdots & \cdots & \cdots \\ \vdots & H_{-1,-1}(s) & H_{-1,0}(s) & H_{-1,1}(s) & \cdots \\ \vdots & H_{0,-1}(s) & H_{0,0}(s) & H_{0,1}(s) & \cdots \\ \vdots & H_{1,-1}(s) & H_{1,0}(s) & H_{1,1}(s) & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{bmatrix}.$$

where $H_{n,m}(s)$. The theoretical work has focused on possibilities to use the HTFs for stability and robustness analysis. We have found

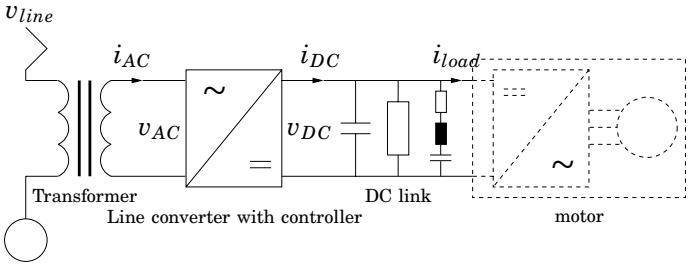


Figure 5.1 A schematic of an inverter locomotive.

that results for linear time-invariant systems can be generalized to this situation. Such results are rare in the literature; noteworthy exceptions are the recent work at by Hall and coworkers at MIT. We are now working to extend these results.

The second line has concentrated on *application of the method on trains*. This is done in cooperation with people from Daimler-Chrysler in Berlin and by Adtranz in Zürich. This contact has evolved into a deeper collaboration which now involve also ABB at Baden-Dätwill. The interest behind the train models comes from the fact that producers of locomotive control systems have had large difficulties with instabilities occurring due to harmonics. Train systems have broken down both in Denmark and Switzerland. It seems that resonances occurring because of oscillation of energy between different frequencies might be a possible explanation. Adtranz has started to analyze this phenomenon using HNE models. A master theses student, Henrik Sandberg, as worked with modeling the motor side of a converter train in a project supervised by ABB, Adtranz and the control department in Lund.

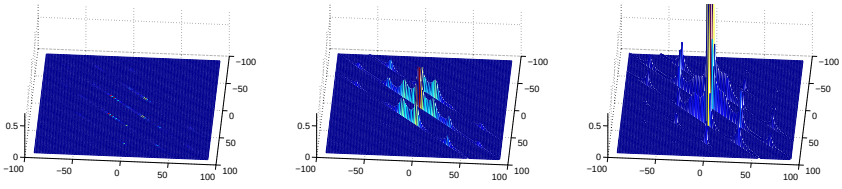


Figure 5.2 Plots showing the amplitude of the coupling between different frequencies for the HTF from Δv_{line} to Δi_{line} for DC-link controller gains $K = 0$, $K = 1$, and $K = 2.23$. The diagonal structure shows that for LTS systems there is interaction between frequencies separated by a multiple of f_0. For $K = 0$, the admittance is zero. By increasing K it is obvious that the DC-link controller leads to interaction with the net.

Dual control

Researchers: Björn Wittenmark, in cooperation with Jan Holst and Bengt Lindoff, Department of Mathematical Statistics, LTH

The dual control problem for time-varying or non-linear systems is inherently analytically and computationally untractable due to the demand of alternating minimizations and mean value computations. Hence, it has to be approached using approximations leading to suboptimal dual control. The core of the successful approximative controller is its ability to be able to consider future expected changes in the development of the parameters.

This research, which is done in cooperation with the Department of Mathematical Statistics, LTH, presents an analysis of the dual-control concept, and a comparison between a number of suboptimal controllers. The analytical comparisons are based on a reformulation of the dual-control problem. The reformulation makes it possible to interpret and understand the nature of the different approximations to dual control, in particular the Adaptive Predictive Controller (APC) and the Active Suboptimal Dual Controller (ASOD). Furthermore, it makes the origin of the computational problems encountered more clear, and suggests new alternatives for approximation. The analysis is carried through on relatively simple examples and simulations. The performance of the controllers when applied to more complicated time-varying systems is also considered.

Modelling and Simulation

Modeling and Simulation of Complex Systems

Researchers: Hubertus Tummescheit, Jonas Eborn, Lennart Andersson and Anders Rantzer

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.

The project started as a computer tool development project and later shifted towards model library development, model language standardization and model reduction methods. The department is an active member of the Modelica effort, which started at a meeting in Lund in 1996. With support from ESPRIT, "Simulation in Europe", the design of Modelica Version 1.0 was finalized in September 1997. Now, with Version 1.3, several companies and universities are providing Modelica based simulation tools. The language definition and other information on the Modelica effort are available on the web site `http://www.Modelica.org`.

The Modelica effort initially considered continuous time systems, since there is a common mathematical framework in the form of differential-algebraic equation (DAE) systems. Our research now extends to 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.

A recent effort within the project has been to combine the experiences of object oriented modeling with basic concepts of robust control. In particular, structured uncertainty and integral quadratic constraints are used to quantify the effects of neglected dynamics and parameter deviations.

Modeling and Control of Energy Processes

Researchers: Karl Johan Åström, Hubertus Tummescheit, Jonas Eborn and Falko Jens Wagner

We have now developed good physics-based nonlinear models that describe steam generators. The models have been used as test cases for model reduction procedures. We have participated in a benchmark on level control in steam generators organized by EDF. Much of the modeling work is now directed towards development of Modelica libraries. Particular attention has been given to media models because we have found that standard media models are not well suited for dynamic simulation. The reason is that the functions that are commonly used do not have a representation that is suitable for dynamic simulation. There are also difficulties with discontinuities. A consequence is that simulations with realistic media models are very slow. We have started to develop efficient techniques for media modeling that are well adapted to dynamic simulation.

System Identification

Researchers: Rolf Johansson in cooperation with 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 discrete-time 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.

When using discrete-time data, it is necessary to make discretization somewhere in the continuous-time identification algorithms. In that context, we have studied approximation properties of a variety of the discretization methods.

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.

Biomedical Modeling and Control

Researchers: Rolf Johansson in cooperation with 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

Process control

Center for Chemical Process Design and Control (CPDC)

Researchers: Karl-Erik Årzén, Tore Hägglund, Ari Ingimundarsson, Rasmus Olsson, Anders Wallén, Björn Wittenmark

The Center for Chemical Process Design and Control (CPDC) is sponsored by the Swedish Foundation for Strategic Research (SSF) and is a cooperation between about ten departments at Chalmers University of Technology, Lund Institute of Technology, and Royal Institute of Technology. The program is administrated from Department of Automatic Control, LTH, and the program director Anders Karlström is located at Chalmers.

The purpose of the program is to look at the interplay between design and control of processes in the chemical process industry. Within CPDC chemical process industry is considered in a wide sense. The program is divided into two main lines of research, continuous processes and batch processes. In the area of continuous processes the applications are mainly within the pulp and paper industry and the batch processes are in the area of manufacturing of chemical substances for medical purposes and for uses in the pulp and paper industry. More information about the program is available at `http://www.control.lth.se/cpdc/`.

The program has a Scientific Advisory Board consisting of

- Guy Dumont, University of British Columbia
- Raficul Gani, Danish Technical University
- John McGregor, McMaster University
- John Perkins, Imperial College

A main activity in CPDC is a graduate school. The first course in the graduate school was performed during autumn 1999. The course was an interdisciplinary course between process and control engineering with emphasis on control. In total there was 14 PhD students participating in the course. The course was divided into two parts, Process Control and Model Predictive Control.

- Part I, Process Control, was introduced in a lecture series by Professor Björn Wittenmark during two days at Chalmers. An interdisciplinary project where process engineering knowledge and requirements meet control engineering design was performed.

- Part II, Model Predictive Control (MPC), was given by Professor Jan Maciejowski from Cambridge University. It was given as a three day seminar series at Lund Institute of Technology. A MPC design of the problem from Part I project was performed.

The research activities are described under different headings in the annual report.

PID Control

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

This project has been in progress since the beginning of the eighties, and resulted in industrial products as well as several PhD theses. Several monographs on PID control that are based on experiences obtained in the project have also been published.

During the last year, the project has focused on PID controller design and extensions of the PID controller. Efficient numerical methods for designing PID controllers based on non-convex optimization have been developed. The design is based on optimization of load disturbance rejection with constraints on sensitivity. Setpoint responses are treated using a two-degree of freedom structure that enables setpoint weighting. If needed, a low-pass filtering of the setpoint is also applied. Finally, measurement noise is handled by the design of a low-pass filter for the measurement signal.

A new controller structure that improves PID control of processes with undamped modes has been developed. The approach has similarities with the deadtime compensating functions that are added to PID controllers to improve control of processes with long deadtimes. The new controller provides active damping of the oscillatory modes.

Autonomous Control

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

This project 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. An interface between Matlab and G2 has been developed to increase the computational power.

Basic process control functions

Researchers: Tore Hägglund and Ari Ingimundarson

This project is a part of NUTEK's research program on Complex Systems, performed in collaboration with ABB Automation Products. The aim of the project is to improve basic control functions used in the process industry and to develop new control functions.

Two projects have been performed during the year. The first is the development of an automatic tuning procedure for deadtime-compensating controllers. The procedure is based on step response experiments performed in closed loop, and process identification through the method of moments.

The second project treats ratio control. Traditional Ratio stations fail to keep the ratio during transients. A new ratio control structure, the Blend Station, that manages to keep the ratio even during transients has been developed. The Blend Station is patent pending.

Control structure design in process control systems
Researchers: Karl Henrik Johansson, Tore Hägglund

Autonomy in process control systems is increasing in importance as a result of growing complexity of industrial systems. The configuration of the controllers is an important factor, although today it is often not considered as a crucial variable when process designs are updated. Control structures in industry have traditionally evolved through years of experience. Rapid development of sensor and computer technology has, however, given new possibilities to make major structural changes in many process designs. This has led to an increasing need for automatic or semi-automatic control structure design tools. Finding a suitable structure or choosing between different structures are in general difficult problems. Even though these type of problems can be regarded as multivariable control problems, little of the activity in multivariable control the last three decades has been devoted to these problems.

The main contribution of this project is an algorithm for control structure design. The algorithm consists of a sequence of experiments that lead to a structural model of the plant, which automatically suggests a control configuration. No prior information about the process is needed. The particular setup is discussed when a SISO control loop is given and a number of extra measurements are available. It is shown that a graph is a natural model for such a system. The graph tells the role each measurement should play in the controller.

Control Loop Monitoring

Researchers: Mikael Pettersson, Tore Hägglund, Karl-Erik Årzén

This project is funded by TFR/SSF in cooperation with ABB Corporate Research, and consists of an industrial PhD-student position for Mikael Pettersson. The focus of the project is monitoring and diagnosis of industrial processes.

During 1999 Mikael Pettersson has investigated control loop monitoring and control structure selection. The scenario studied consists of a SISO PID control loop that contains an additional exogenous signal. The aim is develop methods that automatically decides whether or not the exogenous signal affects the control performance, in which way the exogenous signal affects the control loop, if it is possible to compensate for the exogenous signal by using feed-forward, gain-scheduling or cascade control, and finally how much performance that can be gained by the compensation.

High-Level Grafcet for Supervisory Sequential Control

Researchers: Charlotta Johnsson, Rasmus Olsson, Karl-Erik Årzén

The goal of the project is to extend Grafcet by adding concepts from High-Level Petri nets, and object-oriented programming. The work is based on Grafchart, a Grafcet toolbox that has been developed at the department since 1991. The toolbox is implemented in G2, an object-oriented graphical programming environment.

The main application area of the project is control of recipe-based batch processes. Issues studied include how Grafchart can be used for recipe representation and how this can be integrated with resource allocation. During the year Charlotta Johnsson has defended her PhD thesis “A Graphical Language for Batch Control.”

Control of Biotechnology Processes

Researchers: Mats Åkesson, Lena de Maré, Stephane Velut, and Per Hagander in cooperation with Jan Peter Axelsson, Pharmacia & Upjohn, and Olle Holst, Department of Biotechnology, Lund University

Large-scale production of many enzymes and pharmaceuticals can today be made using genetically modified microorganisms. In so called bioreactors, living cells are grown to large numbers and then made to produce the desired substance. Fed-batch operation, where additional substrate is fed to the culture, is often the preferred way of production. To achieve reproducible cultivations with high cell densities and high productivity, it is important to design good strategies for the substrate-dosage control. A characteristic feature of biological processes is that many important process variables cannot be measured on-line, which complicates the design and realization of feedback strategies.

A project on substrate-dosage control of fed-batch units with genetically modified *E. coli* is performed together with Pharmacia & Upjohn, Process R&D. Information of how to change the substrate feed rate is obtained from standard dissolved oxygen measurements by introducing controlled process perturbations. Tuning rules are derived for the control strategy that assume a minimum of process specific information, and the system is analysed for stability.

The feeding strategy relies on good control of the dissolved oxygen concentration. Variations in the oxygen dynamics during a fed-batch cultivation often cause tuning problems when using a controller with fixed parameters. A control approach based on gain scheduling from the stirrer speed is suggested.

The strategy is now implemented at the Department of Biotechnology, Lund University, at Active Biotech Research, Lund, and at Pharmacia & Upjohn Process R&D, Stockholm, and tested with different *E. coli* strains and operating conditions. Good cultivation conditions and high production levels could be obtained from the first experiment. On December 17, Mats Åkesson defended his PhD thesis “Probing Control of Glucose Feeding in *Escherichia coli* Cultivations”.

The work is funded by NUTEK, “Bioprocesser i industrin”, and by Pharmacia & Upjohn, Process R&D.

Robotics

Robotics Research and Nonlinear Systems Research

Researchers: Rolf Johansson, and Anders Robertsson, in cooperation with Klas Nilsson, Department of Computer Science, LTH

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. 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.

In his doctoral thesis, Anders Robertsson has contributed to theory and algorithm design for observer-based control of nonlinear systems.

Applications

Integrated Control and Scheduling

Researchers: Anton Cervin, Johan Eker, Anders Blomdell, Karl-Erik Årzén

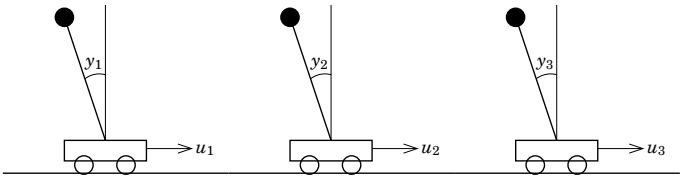
The ARTES project "Integrated Control and Scheduling" is aimed at practical management of hard real-time demands in embedded software. The project consists of two subprojects: "Feedback Scheduling" undertaken by the Department of Automatic Control, Lund University, and "Interactive Execution Time Analysis" performed by the Department of Computer Science, Lund University. Additional project partners are the two real-time software consulting companies Sigma Exallon AB and DDA Consulting, and Professor Lui Sha at the Department of Computer Science, University of Illinois Urbana-Champaign.

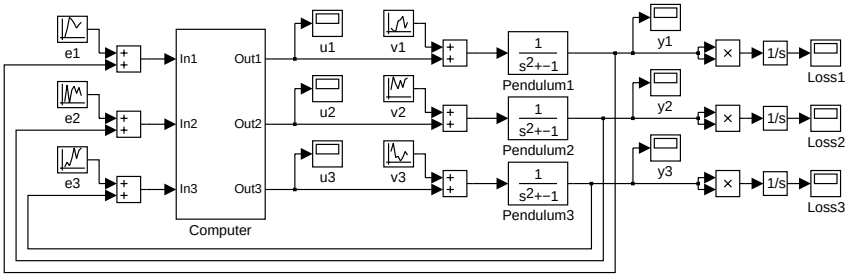
The project finances two ARTES PhD students, Anton Cervin at Automatic Control, and Patrik Persson at Computer Science. The automatic control project team also consists of the PhD student Johan Eker (funded by NUTEK).

During 1999, an in-depth state-of-the-art survey about integrated control and scheduling has been written. The scheduling of the different parts of a control algorithm has been investigated.

A new iterative deadline-based priority assigment scheme has been developed. A MATLAB/SIMULINK based simulator for integrated simulation of controlled processes, control algorithms, and the timing effects caused by a real-time operating system has been implemented. Using the simulator it is possible to study the effects of the task interaction and network delays on control performance, as well as evaluate new feedback scheduling strategies. An example where the kernel is used to control three inverted pendulums is shown in Figure 5.

A novel feedback scheduling algorithm has been proposed. For a





class of LQG-based control systems with convex cost functions, the feedback scheduler calculates the optimal resource allocation pattern. The feedback scheduler can be interpreted as a controller that controls the CPU time utilization of the controller tasks by modifying their sampling frequencies. The optimization is performed so that the global cost is maximized under the constraint that the task set should be schedulable.

Application Specific Real Time Systems: Programming of Control Systems

Researchers: Johan Eker, Anders Blomdell, Karl-Erik Årzén

The goal of the project is to develop flexible programming languages and environments for implementation of real-time control systems. PÅLSJÖ is a software environment for development of embedded real-time systems that has been developed within this project. The engineer off-line defines a set of block which at run-time are instantiated and connected to form a control system. Control algorithms are coded

in a dedicated controller description language called PAL, (PÅLSJÖ Algorithm Language). The system is configured on-line.

Friend, a proposed next generation of Pålsjö/PAL, is a small block based language designed for implementing flexible embedded control systems using contracts and negotiation. A Friend block consists of four parts: the algorithm, the contract, the interface, and the negotiator. The algorithm describes a general control law. The contract describes how and when the controller should be used. The interface describes how the controller is connected to the environments. The negotiator contains platform and hardware specific information. An example of a situation where Friend and its concept can be useful are embedded control system where new control loops are added dynamically. Since it is a real-time system, care must be taken so that computing resources and network resources are divided fairly between the tasks. When the task set changes the task schedule must be recomputed. The idea of "feedback scheduling" can also be realized within Friend.

On December 2, Johan Eker defended his PhD thesis "Flexible Embedded Control Systems - Design and Implementation."

Control of Gasoline Direct Injection (GDI) Engines (FAMIMO)
Researchers: Mikael Johansson, Sven Hedlund, Magnus Gäfvert, Karl-Erik Årzén

FAMIMO (Fuzzy Algorithms for MIMO Control Systems) is a three year Esprit reactive long term research (LTR) project that started 961201. The project has was academic partners and one industrial partner, Siemens Automotive in Toulouse. The project is organized along two benchmark studies: control of a gasoline direct injection (GDI) engine and control of a wastewater fermentation process. During 1999 Mikael Johansson has defended his PhD thesis on piecewise linear systems and Sven Hedlund has presented his licentiate thesis that includes the Matlab toolbox for analysis and synthesis of piecewise linear systems has been developed within the project.

During 1999 the work in the project has focused on control of the GDI engine. A GDI engine can operate in two main modes: homogeneous mode and stratified mode. The homogeneous mode corresponds to the

combustion principle of a normal PFI (Port Fuel Injected) gasoline engine where fuel is injected during the air intake stroke. In the stratified mode, fuel is injected during the compression stroke which makes it possible to employ high air/fuel ratios, leading to lower fuel consumption. The GDI engine is more complex than an ordinary PFI engine and therefore requires a more advanced control system. Special care must be taken to the combustion mode switches.

The goal is to design an engine management system (controller) that follows the reference signals from the driving cycle while minimizing fuel consumption and emissions, and maintaining the driving comfort. During 1998 three different control designs were developed for a reduced benchmark where the driver model is excluded and the set-points to the controller are pre-calculated torque references. The nature of the three controller ranges from a fairly conventional engine control design based on extensive use of nonlinear engine maps, to a controller based on linear feedback and feed-forward structures combined with extremum seeking control for finding the optimal operating point in stratified mode.

During 1999 the linear control design has been further developed. The controller has been evaluated on the full European driving cycle scenario including driver model and sensor noise with very promising results.

Motion Control of Open Packages Containing Fluid

Researchers: Mattias Grundelius, Bo Bernhardsson

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. The focus in the project has been movement of open packages containing liquid. All packages in the

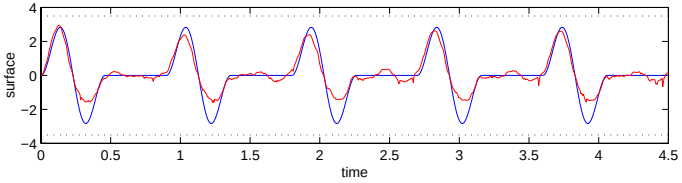


Figure 5.3 The container is moved five times using an acceleration reference calculated with the minimum energy approach showing the surface elevation, simulation and measurements. The movement length of each step is 0.2 m, the movement time is 460 ms and the time between each movement is 440 ms. The figure shows that the measured surface elevation is close to the simulated except that the negative peak is much smaller. The residual oscillation between the movements is small and does not affect the performance in a negative way, i.e. the maximum surface elevation is not increasing.

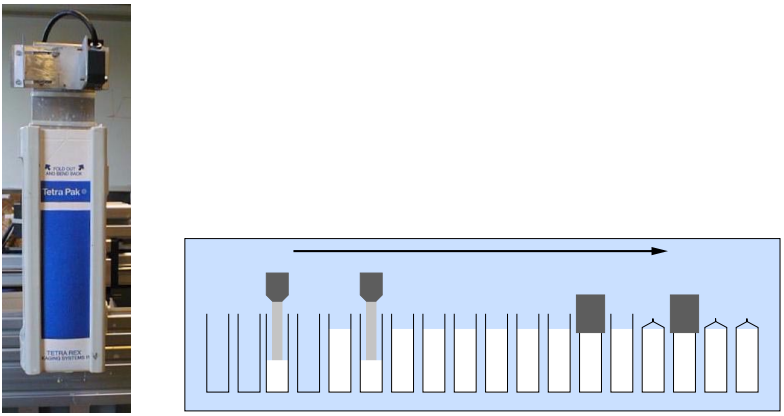


Figure 5.4 Experimental equipment (left). Schematic picture of filling machine (right)

machine follow the same acceleration profile. Between the filling station and the sealing station the package is moved one or several times. The aim is to find the acceleration profile that minimize the movement time with a maximum allowed slosh.

The results have been implemented and used in the Tetra Pak plant in Chicago. The implementation has resulted in improved production speed. It has also been accepted as being conceptually sound by the development engineers. Equipment that can measure the surface elevation has been acquired. A simple slosh model has been derived. Both minimum-time and minimum-energy acceleration profiles have been calculated. The various acceleration profiles have been evaluated in the experimental setup with good results. Comparison with the acceleration profiles used in practice has also been done showing the advantage of the calculated acceleration profiles.

The project is funded by NUTEK under the Regina program. It is performed in collaboration with Tetra Pak Research & Development AB in Lund, who has supplied the experimental equipment.

Automotive Systems: Adaptive Cruise Control and Driver Models

Researchers: Rolf Johansson, Johan Bengtsson (in cooperation with Erik Hesslow, Volvo Technical Development, Inc., Gothenburg)

This project is directed towards adaptive cruise control for automotive application in dense traffic and in conditions of automated highways. Radar sensing with Doppler-shift measurement permits feedback to maintain relative distance and relative velocity to vehicles ahead. A stop-and-go controller for adaptive cruise control has been developed, tested and reported. Current work is directed towards driver-model support.

Modeling and control of processes in the steel industry

Researchers: Lars Malcolm Pedersen, Björn Wittenmark, in cooperation with the Danish Steel Works

The project was completed with the PhD thesis by Lars Malcolm Pedersen. The last part of the project was modeling and control of reheat furnaces. The main purpose with a reheat furnace is to heat steel blocks (slabs) from outdoor temperature to a temperature of approximately 1120° C before they are processed in the rolling mill. The weight of the slabs is about 10 tons each and the furnace contains

Figure 5.5 A discharged slab ready for rolling. (Photo: Dag Toijer, Automation)

about 60 slabs at a time. Each slab is heated for about 5 hours. At the discharge end of the furnace it is important that the slabs have a prespecified temperature and that the temperature gradients in the slabs are as small as possible. It is also important to be able to handle production variations, such as stops in the rolling mill.

Within the project new models and control strategies have been developed. The models are verified using data collected at the Danish Steel Works. The model has been optimized using Matlab and the model has been evaluated using the program Femlab developed by Comsol. Femlab is a simulation package for partial differential equations based on finite element techniques. Using the models a new control strategy has been derived. The controller contains three parts. The first part is

a feedforward from production to be able to cope with the speed of the slabs through the furnace. The second part in the controller is a new heating curve, desired temperature profile, for the furnace. The third part is a gainscheduled PI-controller using the heating curve as the reference signal and a computed center temperature of the slabs as the measurement variable. The control algorithms have been implemented and tested in production for several months. The tests indicate that the production can be increased between 5 and 10% without increasing the energy for heating. The new algorithm will also be implemented at other furnaces at the Danish Steel Works.

The control system can be simulated using Femlab at
`http://webmodels.femlab.com/slab/index.html`

Distributed Control of Safety Critical Mechanical Systems

Researchers: Bo Bernhardsson, Magnus Gäfvert, Björn Wittenmark, in cooperation with Department of Computer Engineering, CTH, Department of Mechanical Elements, KTH, and Volvo

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

Case study As a means to combine methods and theory from automatic control, computer engineering, and mechatronics in the field of distributed safety-critical control systems, a case study has been initiated in cooperation with Volvo Technological Development (VTD). The subject of the study is an electrical braking system with integrated anti-lock and yaw-control functionality for heavy duty tractor-trailer combinations. The case study was started up in 1999 with a literature study and a study of present electrical braking systems at Volvo as a first step. A study of a present system has been presented in a report. Then a fairly detailed simulation model of the vehicle has been constructed, which will be used to investigate properties of different

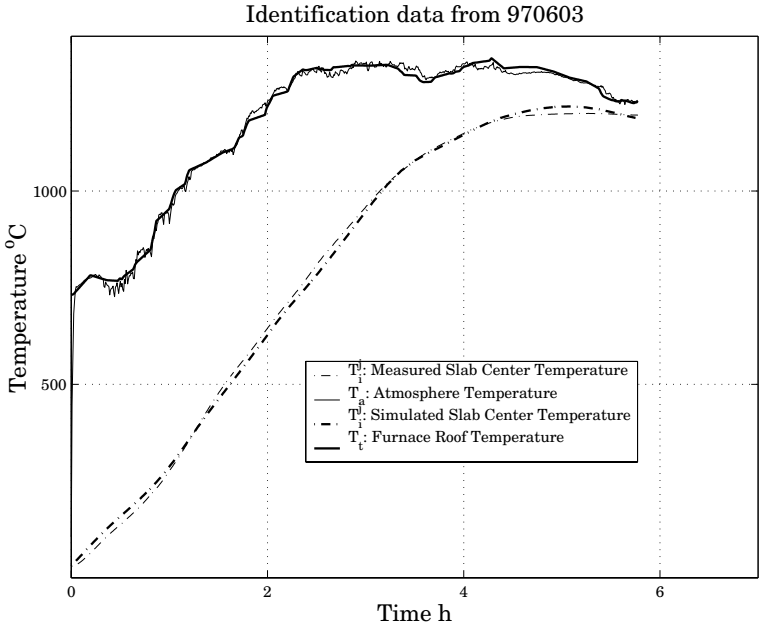


Figure 5.6 Results of system identification of the ODE for the slab center temperature. The plot shows the furnace roof temperature T_t, the measured pig center temperature T_i^j, and the simulated temperature T_i^j.

system designs. The study is expected to result in new insights in design and development methods for dependable distributed control systems. Three graduate students are active in the case study: Magnus Gäfvert (Department of Automatic Control), Vilgot Claesson (Department of Computer Engineering, CTH), and Martin Sanfridsson (Mechatronics Lab, KTH). The work during 1999 was concentrated to 10 weeks when the graduate students worked together at VTD. This enabled a closer cooperation, with the possibility to develop cross-disciplinary ideas and thoughts.

Timing problems in real-time systems The work with communication delays presented in the thesis by Johan Nilsson has continued. Synchronous and asynchronous nets have been analyzed with respect to timing and delays. A typical example is control over a field-bus where the input-output unit is sampling with one sampling period, the message is sent over a field-bus with a second sampling period, and finally the control algorithms is executed with a third sampling period. This kind of layered communication can give rise to surprisingly long communication delays, which are very sensitive to the timing in the different parts of the system. The project continues with work on different control strategies.

Robustness Analysis of the Scandinavian Power Network
Researchers: Anders Rantzer and Lennart Andersson

The purpose of this project is to take advantage of recent computer tools for large scale robustness analysis, in order to analyse a dynamic model of the Scandinavian power transmission network.

The model includes 16 generators, 16 power loads, and 20 transmission lines. There are totally 16 inputs, 16 outputs, 127 states, and more than 500 parameters. One objective is to compute the maximal range of parameter variations for which this equilibrium remains locally stable. Even if the number of uncertain parameters is restricted, the size of this problem is challenging.

Algorithms for structured singular value computations can handle matrices of dimension as high as 50–100, but not many problems of this size have been treated in the literature. One reason is that proper generation of input data for large problems is a non-trivial task. Our approach is the following: Using a large nonlinear differential-algebraic model, a power system can be simulated and a stable equilibrium can be found. The system equations are then linearized symbolically and transformed into the format for robustness analysis in Matlab.

The project is done in contact with Sydkraft and the Department of Industrial Electronics and Automation at Lund Institute of Technology.

Cardiologic Analysis and Modeling

Researchers: Rolf Johansson in cooperation with Magnus Holm and 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.

6. External Contacts

The roles of the universities in technology transfer has recently been emphasized in Swedish research policy as “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 Power Systems
ABB Robotics
ABB SuHAB
Active Biotech Research AB
Alfa Laval Automation,
The Danish Steel Works Ltd.,
Danfoss AS,
DDA Consulting,
Diana Control AB,
Dynasim AB,
Elforsk,
Gensym Corp.,
Pharmacia & Upjohn,
Sigma Exallon AB,
Siemens Automotive,
Sydkraft,
Tetra Pak Research & Development,
Volvo Technical Development.

We have had smaller projects with

Astra Draco,
Astra Hässle,
Alfa Laval Thermal,
Cellavision,
Comsol,
Ericsson,
Haldex Traction

Industrial Communications,
MEFOS,
Modo Paper Husum,
Novotek,
Pulp and Paper Industries Engineering Co. (STFI),
SIK – Institutet för livsmedel och bioteknik AB,
Stora Hylte AB
Vattenfall.

and meetings and discussions with many other companies.

European Collaboration

We are 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 (`http://iridia.ulb.ac.be/~famimo/`).

We are also member of the ESPRIT longterm project *Heterogeneous Hybrid Control (H2C)* with three academic partners and DaimlerChrysler as an industrial partner (`http://www.control.lth.se/H2C/`).

Figure 6.1 Rolf Braun demonstrates a new laboratory process to Karl Johan Åström. It is a centrifugal controller made from glass. Boel Flodgren, vice-chancellor of Lund University, is also fascinated.

The Åström Symposium

A highlight of the year was the Åström Symposium on August 28, which was organized in honor of Karl Johan Åström who retired from his professor position by the end of 1999. The symposium had ten specially invited speakers with outstanding international reputation and a personal relationship to Karl Johan. More than 200 people attended the symposium and a dinner was held in Trolleholm castle.

Each of the ten speakers wrote a contribution to a book (see Publication list) aimed to illustrate the breadth, width, and depth of Karl Johan's professional work and to point out new directions within the different fields. Karl Johan's interest in process control applications such as paper machine control dates back the early sixties. The developments in the field since then were reviewed by *Guy A. Dumont* with the perspective of Åström's contributions. The topics included modeling, stochastics, adaptation, robustness, and nonlinearities, issues that were

also specifically addressed in the remaining chapters.

Lennart Ljung discussed model validation and how model deficiencies can be visualized using error models. This relates directly to Karl Johan's persistent interest in system identification. The idea to update system models and controllers continuously based on measured data has been pursued by Karl Johan for a long time in the context of adaptive control. New perspectives on such learning processes were presented in the two contributions by *M. Vidyasagar* and *Marco C. Campi* and by *Marco C. Campi* and *P. R. Kumar*.

In cases where good system models of moderate complexity can be achieved, they can be used to optimize the control performance. On-line optimization of this kind was discussed in the chapter by *Graham C. Goodwin*, *Mónica E. Romero*, and *María M. Seron*. In other cases, the system complexity is so high that a detailed model is impractical for controller design. This was the situation treated in the contribution by *Roger W. Brockett*. Moreover, *John C. Doyle* argued in the final chapter that high complexity not only causes practical problems. It also leads to fundamental restrictions related to robustness.

The effects of nonlinearities in control systems have also attracted considerable attention by Karl Johan. This was the subject of three chapters. *Richard M. Murray* discussed rate and magnitude saturation from a perspective of geometric nonlinear control. *Masaki Yamakita* and *Katsuhisa Furuta*, who worked jointly with Karl Johan on swing-up strategies for inverted pendulums, extended their ideas towards robust state-transfer for double pendulums. Finally, *Alberto Isidori* addressed nonlinear stabilization using output feedback.

The book also includes a short biography which tries to capture some features of a quickly moving target. A bibliography was compiled, covering thesis, books, published papers, and conference contributions. The list covers more than 40 years of scientific work.

7. Looking back — Research Interaction with Neuroscience

Feedback control is important in many physiological contexts and one such context is the balancing of the standing human-i.e., an inverted pendulum. Human posture control is maintained by proprioceptive, vestibular, and visual feedback, integrated within the central vestibular and locomotor system. Lesions to the sensory feedback system, or to the central nervous system, may impair postural control and equilibrium. Such lesions presents themselves as unsteadiness, dizziness, vertigo and cause problems to large populations of patients-not the least among the elderly. Patient problems include vertigo, dizziness, imbalance, nausea, and motion sickness. Because the vestibular system interacts with many other parts of the nervous system, symptoms may also be experienced as problems with vision, muscles, thinking and memory. Problems may be caused by infection, head trauma, tumors or as side effects of pharmaceutical and illegal drugs. Problems of vertigo, imbalance and motion sickness are usually treated by physicians with a specialist background in neurology or in ear-nose-throat diseases (ENT or otorhinolaryngology).

The Vestibular Laboratory or Balance Laboratory, Dept. Otorhinolaryngology, Lund University Hospital, has a strong tradition that dates back at least a century. The ENT Clinic at Lund University was founded in 1899 with Dr. Frans Törne as its first specialist. Dr. Gösta Dohlman had his education from Prof. Robert Bárány in Uppsala and he acted in Lund from 1930 and from 1939 to 1956 as Professor and Head of Department. (Robert Bárány was awarded the Nobel Prize in 1914 for research that clarified the physiology and pathology of the human vestibular apparatus.)

In 1956 Dr. Nils G. Henriksson defended his thesis entitled “Electrical Analysis of Eye Movements in Nystagmus” with Jongkees as faculty opponent. He made early contributions to diagnosis of balance disor-

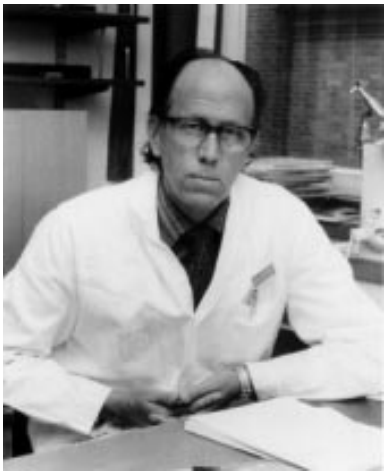


Figure 7.1 Docent Nils G. Henriksson, Vestibular Laboratory, Lund Univ. 1970

ders. During post-doctorate work around 1960 with Lindsay, Fernandez and Fredrickson at University of Chicago he made early studies of adaptation phenomena of the vestibulo-ocular reflex—i.e., the neural circuit that provides information from the balance organ about the acceleration of the head and permits the gaze to remain fixed in space during head motion. During that time he established an important international network of scientific contacts which he maintained throughout his life. Back in Lund he established the Vestibular Laboratory at the ENT Clinic of Lund University Hospital and he acted as Head of the Vestibular Laboratory under Prof. Hjalmar Koch (1956-1976) and Prof. Carl M. Eneroth (1976-1992). A large number of young, now prominent, researchers—e.g., Ilmari Pyykkö (Stockholm), Robert Kohut (Winston-Salem, NC), Wallace Rubin, C.F. Pfaltz (Basel), Claus F. Claussen (Würzburg)—visited Henriksson's laboratory in Lund. In contrast to many contemporary colleagues, Henriksson did not limit his interest to mechanical analysis but made early efforts towards system analysis of neurological systems interacting with biomechanics. Neurological adaptation phenomena and feedback have remained important domains of research ever since Henriksson's early observations.

The scientific community of those years had a strong impact from

the early space programs and the associated questions of motion sickness and orientation in man-vehicle systems. Moreover, both the formulation and answers to problems of interaction among neurologic and biomechanical subsystems require the expertise from the system and control area. An important such example of interaction is the standard explanation of the physiological basis of vertigo and motion sickness. According to such hypotheses, motion sickness results from sensory mismatch among the visual, vestibular and proprioceptive sensory systems and that no consistent feedback can be produced from such contradictory sensory information. Hence, motion sickness is explained as a sensor-fusion failure.

Naturally, the co-existence in Lund of a control department and a strong laboratory specializing in balance disorders stimulated cooperation on issues of mutual interest. Henriksson and Haldo Östlundh, a neurologist with a research interest in postural control, started cooperation with Dept. Automatic Control with Ivar Gustavsson and Per Hagander on data analysis. Östlundh had an interest to assess the ability of postural control by measuring the displacement of the body center of gravity during spontaneous body sway [Henriksson *et al.*, 1967; Kjellander and Selander, 1972]. A few years later, effects of this interaction on control research were visible in the publications [Gustavsson *et al.*, 1973; Wieslander, 1976; Östlundh, 1979].

IDPAC was an interactive command-driven program for data analysis and system identification in which user interaction was accomplished by means of a subroutine package called INTRAC. IDPAC was a team work led by Prof. K.J. Åström that except for Wieslander and Gustavsson also involved L. Ljung, T. Söderström, and others. IDPAC was one of the first identification packages and contained functionality for data and file management, spectrum analysis, covariance analysis, discrete linear model identification using maximum-likelihood and least-squares estimation, simulation and statistical model validation. The objectives of such system identification software development were more far-reaching than neurodynamics only. Nevertheless, behind this general-purpose identification package were people like Ivar Gustavsson and Staffan Selander who both made balance experiments as well as programming.

After Matlab emerged around 1980, L. Ljung continued the interactive identification using the interaction facilities offered by Matlab. Thus, a great deal of IDPAC functionality re-appeared in the framework of Matlab Identification Toolbox and support of IDPAC ended around 1986.

In 1986, after Henriksson's retirement, the laboratory leadership was effectively taken over by Dr. Måns Magnusson who had recently defended his thesis entitled "On the optokinetic mechanism in man and rabbit". Henriksson, still active after retirement, and Magnusson got in contact with Rolf Johansson and started cooperation using a refined experiment set-up based on the idea of injection of reproducible perturbations into the feedback loops, thus providing a basis for effective investigation of the contribution of each feedback loop and their malfunction in disease. A research program funded by the Medical Research Foundation (MFR) was set up to investigate various aspects of 'sensor fusion' present in human neurophysiology of balance and stance. New engineering staff was recruited (Per A. Fransson). Meanwhile, Johansson continued the tradition of system identification. Although the main point of interest was neurophysiological, there was also an aspect of biomechanics in research. Such biomechanical aspects often took on the form of 'inverse robotics' and inspired work in robotics, optimal control and inverse optimality.

There was also a great deal of international attention to a number of doctorates at Vestibular Laboratory co-supervised by Måns Magnusson and Rolf Johansson [Enbom, 1990; Brantberg, 1991; Padoan, 1992; Petersen, 1995; Karlberg, 1995]. Although all these Ph. D. theses were made by physicians, a great deal of the subject matter was system identification and its application to physiology. The medical research community found the approach to be innovative. Aside from the interest among physicians of otorhinolaryngology, there was also a clear impact in the fields of neurology and physical medicine. In these fields there was a particular appreciation for the quantitative power and the potential of system identification as a quantitative means to monitor rehabilitation.

Whereas analysis of spontaneous motion gives ambiguous results,

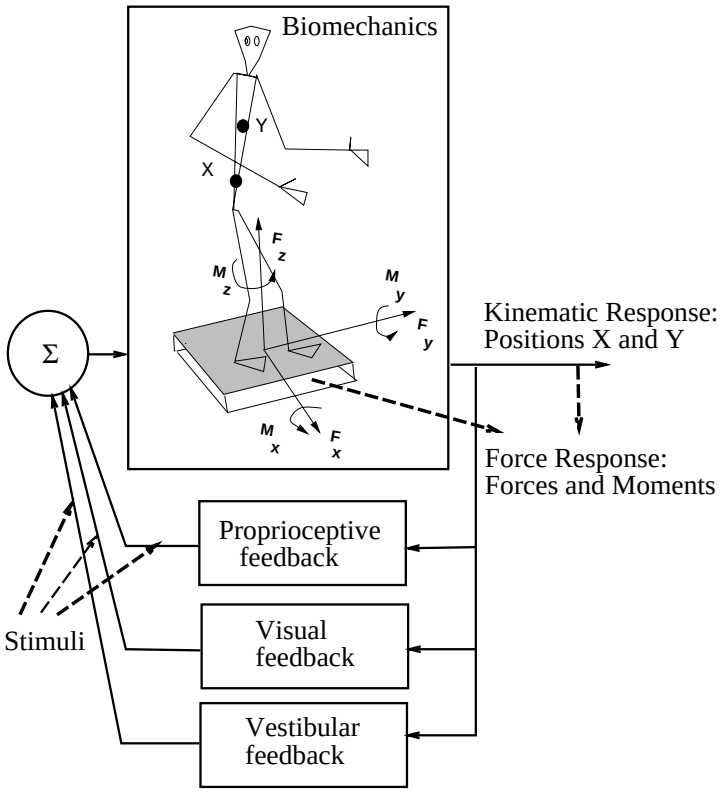


Figure 7.2 Investigation of postural control

analysis of induced motion proved to be a key to success. Stability of postural control may thus be investigated by means of perturbations to the visual, vestibular and proprioceptive sensory feedback systems (Fig. 7.2). Among suitable such stimuli are mechanical vibration applied to muscle spindles, galvanic stimulus applied to the mastoids and virtual-reality illusions. Measurements are provided among kinematics of body segments, six degrees-of-freedom support forces and EMG. There are several issues of experiment design in order to satisfy conditions

of sensitivity, specificity, persistency of excitation and patient safety. By means of system identification applied to the multi-loop feedback dynamics, it is possible to evaluate the function and contribution to stability of specific feedback loops. System identification may thus provide quantitative diagnostic tools that describe the human ability to maintain posture. The methods developed are used in diagnosis and to monitor rehabilitation of human balance disorders.

Dr. Nils G. Henriksson, Assoc. Professor, passed away on March 10, 1999.

References on Interaction with Neuroscience

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Enbom, Håkan: *Vestibular and Somatosensory Contributions to Postural Control*. PhD thesis MERL 1027, Dept. Otorhinolaryngology, Lund University Hospital, Lund, Sweden, October 1990.

Gustavsson, I., S. Selander, and J. Wieslander: "Idpac user's guide." Technical Report ISRN LUTFD2/TFRT--7331--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, October 1973.

Henriksson, N. G., G. Johansson, L. G. Olsson, and H. Östlund: "Electrical analysis of the Rhomberg test." *Acta Otolaryngol. Suppl.*, **224**, pp. 272–279, 1967.

Johansson, R., M. Magnusson, and M. Åkesson: "Identification of human postural dynamics." *IEEE Trans. Biomedical Engineering*, **3**, pp. 858–869, 1988.

Karlberg, Mikael: *The Neck and Human Balance*. PhD thesis MERL 1040, Dept. Otorhinolaryngology, Lund University Hospital, Lund, Sweden, November 1995.

Kjellander, Birger, and Staffan Selander: "Balansförmåga — mätningar och analys med processdator," (Balance—measurements and analysis with a process computer). Master thesis ISRN LUTFD2/TFRT--5604--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, 1972.

Östlundh, H.: "A study of aim and strategy of stability control in quasistationary standing." PhD thesis, Dept. of Neurology, S:t Lars Hospital, Lund, Sweden, 1979.

Padoan, Serge: *Effects of Some Anaesthetics on Eye Movements and Postural Control*. PhD thesis MERL 1036, Dept. Otorhinolaryngology, Lund University Hospital, Lund, Sweden, June 1992.

Petersen, Hannes: *The Inner Ear and Postural Control in Man*. PhD thesis MERL 1039, Dept. Otorhinolaryngology, Lund University Hospital, Lund, Sweden, October 1995.

Wieslander, Johan: "IDPAC—User's Guide." Technical Report ISRN LUTFD2/TFRT--3099--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, 1976.

8. Dissertations

Seven PhD theses were defended by Charlotta Johnsson, Mikael Johansson, Lars Malcolm Pedersen, Lennart Andersson, Johan Eker, Anders Robertsson, and Mats Åkesson; and one Lic Tech thesis was completed by Sven Hedlund.

The abstracts are presented here in chronological order.

A Graphical Language for Batch Control

Charlotta Johnsson
PhD dissertation, March 25, 1999

Opponent: Prof. Dr.-Ing. Sebastian Engell, University of Dortmund, Germany. Committee: Prof Sten Bay Jorgensen, Technical University of Denmark; Prof Bo Egardt, Chalmers University of Technology, Sweden; Ph.D. Jan Peter Axelsson, Pharmacia & Upjohn, Sweden; Ass. Prof. Bernt Nilsson, Lund Institute of technology, Sweden.

In this thesis a graphical language for sequential control is presented and its application to batch control is examined and discussed. The name of the language is Grafchart. Its main feature is that it makes it possible to express complicated control problems in a compact and intuitive manner.

Grafchart exists in two versions; a basic version and a high-level version. The basic version was available when the work presented in this thesis started. The basic version of Grafchart is mainly based on Grafcet, i.e., it has a clear and intuitive syntax. In addition to this it has support for parameterization and methods and message passing as well as extended facilities for exception handling. The high-level version of Grafchart takes the concepts of the basic version one step further. The concepts of object tokens and multi-dimensional charts are introduced. These features are inspired by high-level Petri nets and constructs from object-oriented programming languages.

The main application area of Grafchart is batch control. In the thesis it is shown how Grafchart can be used for recipe structuring and recipe analysis. By using the features of Grafchart in various ways, recipes can be given different structures with different advantages and disadvantages. All structures comply with the international batch standard IEC 61512 (also refered to as ISA S88.01). The batch recipe structures can be combined with resource allocation and transformed into an equivalent Petri net structure whereby formal analysis methods that exist for Petri nets can be used to look for possible deadlock situations.

Several commercial batch control systems exist today. They all have a similar approach to recipe structuring, resource allocation and user presentation. The advantages of using Grafchart compared to some of these systems are presented in the thesis. A toolbox implementation of Grafchart exists. It is implemented in G2, an object-oriented programming environment.

Piecewise Linear Control Systems

Mikael Johansson
PhD dissertation, March 26, 1999

Opponent: Prof. Stephen Boyd, Stanford University. Committee: Prof. Lennart Ljung, Linköping University, Sweden; Prof. Rodolphe Sepulchre, University of Liege, Belgium; Ph.D. Krister Forsman, ABB Corporate Research, Malmö, Sweden

This thesis treats analysis and design of piecewise linear control systems. Piecewise linear systems capture many of the most common nonlinearities in engineering systems, and they can also be used for approximation of other nonlinear systems. Several aspects of linear systems with quadratic constraints are generalized to piecewise linear systems with piecewise quadratic constraints. It is shown how uncertainty models for linear systems can be extended to piecewise linear systems, and how these extensions give insight into the classical trade-offs between fidelity and complexity of a model.

Stability of piecewise linear systems is investigated using piecewise quadratic Lyapunov functions. Piecewise quadratic Lyapunov functions are much more powerful than the commonly used quadratic Lyapunov functions. It is shown how piecewise quadratic Lyapunov functions can be computed via convex optimization in terms of linear matrix inequalities. The computations are based on a compact parameterization of continuous piecewise quadratic functions and conditional analysis using the S-procedure. A unifying framework for computation of a variety of Lyapunov functions via convex optimization is established based on this parameterization. Systems with attractive sliding modes and systems with bounded regions of attraction are also treated.

Dissipativity analysis and optimal control problems with piecewise quadratic cost functions are solved via convex optimization. The basic results are extended to fuzzy systems, hybrid systems and smooth nonlinear systems. It is shown how Lyapunov functions with a discontinuous dependence on the discrete state can be computed via convex optimization. An automated procedure for increasing the flexibility of the Lyapunov function candidate based on linear programming duality is suggested. A Matlab toolbox that implements several of the results derived in the thesis is presented.

Modeling and Control of Plate Mill Processes

Lars Malcolm Pedersen
PhD dissertation, May 25, 1999

Opponent: Bo Egardt, Chalmers University, Gothenburg, Sweden. Committee: Prof. Torkel Glad, Linköping University, Sweden; Prof. Jacob Stoustrup, Ålborg University, Denmark; Ph.D. Bo Leden, MEFOS, Luleå, Sweden

In this thesis two processes have been modeled and controlled, namely the plate thickness control and the slab temperature control. The classical solution for the thickness control problem can't handle asymmetric hardness variations and the estimation of the controlled output introduces stability problems. A nonlinear multivariable model for the thickness control system is derived. The parameters of the model for the rolling

mill are identified using data from The Danish Steel Works Ltd. and the model is used for designing a nonlinear multivariable thickness control algorithm. The algorithm is evaluated using computer simulations and the new controller is able to handle the asymmetric case and gives a more accurate thickness control compared to the existing control system. The new control strategy is also found to be stable.

The task of the slab temperature controller is to ensure a high furnace throughput, and a proper heating quality while minimizing the energy consumption. Models for the slab and furnace temperatures are identified using data collected during normal production at The Danish Steel Works Ltd. A new way of obtaining parameters for the existing slab temperature control system is described. Furthermore, a nonlinear controller is designed which it is shown to be is globally asymptotically stable. The performance of the linear and nonlinear controller are compared using computer simulations which show that the performance of the nonlinear controller is superior to the performance of the linear controller.

The linear slab temperature controller design has been implemented in the slab temperature control system at The Danish Steel Works Ltd. The experimental results indicate that the new controller parameters have lead to a 10% increase in furnace capacity, with unchanged heating quality. Data from the reheat furnace no. 2 indicate that the energy consumption has not been increased by the adjustments.

Computational Methods for Hybrid Systems

Sven Hedlund
Lic Tech dissertation, September 17, 1999

Opponent: Jan van Schuppen, CWI, Amsterdam, The Netherlands

This thesis considers two different computational approaches for the analysis and synthesis of nonlinear systems. Each of these approaches is presented in a conference paper that describes parts of the theory and algorithms. MATLAB commands implementing the algorithms have been developed and the manuals for these are included herein as well.

The systems being considered are piecewise linear systems and a more general class of nonlinear hybrid systems. The piecewise linear systems are analyzed by means of piecewise quadratic Lyapunov functions. The analysis includes stability tests, L_2-gain, and output energy estimation. Synthesis based on optimal control using piecewise quadratic cost functions is also presented in terms of bounds on the value function and the corresponding piecewise linear feedback control.

The computational methods for the more general class of hybrid systems focus on optimal control. A hybrid system is in this thesis defined as a set of continuous systems (modes) and a discrete variable that keeps track of the current mode. A value function is computed from a cost function that penalizes the continuous states as well as mode switches. A nonlinear feedback control law is derived based on the value function.

The MATLAB commands and accompanying examples are available upon request from the author.

On Simplification of Models with Uncertainty

Lennart Andersson
PhD dissertation, September 24, 1999

Opponent: Prof. David Limebeer, Imperial College, London, Great Britain. Committee: Prof. Bo Wahlberg, KTH, Stockholm, Sweden; Docent Sture Lindahl, ABB Generation AB, Västreråas, Sweden; Prof. Gustaf Olsson, IEA/ LTH, Lund, Sweden

Mathematical models are frequently used in control engineering for analysis, simulation, and design of control systems. Many of these models are accurate but may for some tasks be too complex. In such situations the model needs to be simplified to a suitable level of accuracy and complexity. There are many simplification methods available for models with known parameters and dynamics. However, for models with uncertainty, which have gained a lot of interest during the last decades, much needs to be done. Such models can be used to capture for example parametric uncertainty and unmodeled components and are important both in theory and applications.

In this thesis, error bounds for comparison and simplification of models with uncertainty are presented. The considered simplification method is a generalization of the Balanced truncation method for linear time-invariant models. The uncertain components may be both dynamic and nonlinear and are described using integral quadratic constraints.

The thesis also considers robustness analysis of large nonlinear differential-algebraic models with parametric uncertainty. A general computational methodology based on linearization and reduction techniques is presented. The method converts the analysis problem into computation of structured singular values, while keeping the matrix dimensions low. The methodology is successfully applied to a model of the Nordel power system.

An overview of model simplification is also given.

Flexible Embedded Control Systems. Design and Implementation

Johan Eker
PhD dissertation, December 2, 1999

Opponent: Bruce Krogh, Carnegie-Mellon University, USA. Committee: Prof. Lars Nielsen, Linköping University, Sweden; Ph.D. Ola Dahl, DDA Consulting, Malmö, Sweden; Ph.D. Ken Tindell, Northern Real-Time Applications, York, Great Britain.

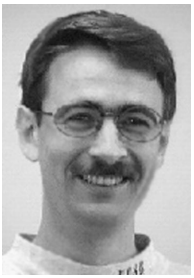
Embedded control system design is a complex and error prone task, and there is a great need for better development tools. Today most real-time control systems are static systems, designed in an ad-hoc fashion. A more interactive way of working would give shorter development times, reduced costs for testing, and safer, more robust systems. The static nature of most embedded control systems makes them sensitive to changes in the hardware or software configuration. There is rarely any interaction between the control loops and the underlying real-time kernel or operating system. From a control engineering perspective, the system executes in open loop. This thesis presents an interactive prototyping tool called Pålsjö and a controller description language called PAL. Pålsjö allows the user to interactively configure a system. Control systems are defined using block diagrams and blocks may be added and replaced on-line.

The possibility of using feedback in the scheduling of real-time tasks is explored. This is called feedback scheduling. An algorithm for selecting sampling rates based on the linear quadratic cost is presented. The dependence of the cost function on the sampling interval is investigated.

The influence on the control performance from the interaction between the control tasks running concurrently in the real-time kernel is studied. A simulation toolbox for this type of simulations is presented in the thesis.

Designing flexible control systems is much simplified given the proper language support. Therefore the PAL language concept is extended into a new proposed language Friend, which is designed to support the development of flexible embedded control systems through the use of contracts.

On Observer-Based Control of Nonlinear Systems



Anders Robertsson
PhD dissertation, December 16, 1999

Opponent: Bruno Siciliano, Università degli Studi di Napoli Federico II. Committee: Prof. Torkel Glad, Linköping University, Sweden; Prof. Thor I. Fossen, Norwegian University of Science and Technology, Trondheim, Norway; Prof. M. Blanke, Technical University of Denmark, Lyngby, Denmark; Dr. Sven Erik Mattsson, Dynasim AB.

Filtering and reconstruction of signals play a fundamental role in modern signal processing, telecommunications, and control theory and are used in numerous applications.

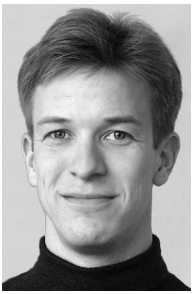
The feedback principle is an important concept in control theory. Many different control strategies are based on the assumption that all internal states of the control object are available for feedback. In most cases, however, only a few of the states or some functions of the states can be measured. This circumstance raises the need for techniques, which makes it possible not only to estimate states, but also to derive control laws that guarantee stability when using the estimated states instead of the true ones. For linear systems, the *separation principle* assures stability for the use of converging state estimates in a stabilizing state feedback control law. In general, however, the combination of separately designed state observers and state feedback controllers does not preserve performance, robustness, or even stability of each of the separate designs.

In this thesis, the problems of observer design and observer-based control for nonlinear systems are addressed. The deterministic continuous-time systems have been in focus.

Stability analysis related to the Positive Real Lemma with relevance for output feedback control is presented. Separation results for a class of nonholonomic nonlinear systems, where the combination of independently designed observers and state-feedback controllers assures stability in the output tracking problem are shown. In addition, a generalization to the observer-backstepping method where the controller is designed with respect to estimated states, taking into account the effects of the estimation errors, is presented. Velocity observers with application to ship dynamics and mechanical manipulators are also presented.

Probing Control of Glucose Feeding in *Escherichia coli* Cultivations

Mats Åkesson
PhD dissertation, December 17, 1999



Opponent: William E. Bentley, University of Maryland. Committee: M.Sc. Anders Eriksson, Astra Carotene, Gustavsberg, Sweden; Prof. Alf Isaksson, KTH, Stockholm, Sweden; Prof Gustaf Olsson, IEA/LTH, Lund, Sweden; Prof. Gunnar Lidén, Kemisk Teknologi, Lund, Sweden

Production of many proteins can today be made using genetically modified organisms. One of the most frequently used host organisms is the bacterium *Escherichia coli*. A difficulty encountered in cultivations of *E. coli* is the accumulation of the metabolic by-product acetate which inhibits cell growth and production of a desired protein. Formation of acetate occurs under anaerobic conditions but also in situations with excess of the carbon/energy source that usually is glucose. In fed-batch processes the glucose feed rate can be manipulated to avoid acetate formation, but most feeding strategies require considerable process knowledge to handle process variations. On-line measurements for the relevant process variables are far from being standard which complicates the realization of strategies based on feedback control.

This thesis presents a glucose feeding strategy for *E. coli* cultivations that avoids acetate formation in spite of process variations and without prior knowledge of the particular strain and product. The key idea is to exploit a characteristic saturation in the cellular respiration at the onset of acetate formation. By superimposing short pulses in the glucose feed rate, on-line detection of acetate formation can be made using a standard dissolved oxygen sensor. This information is used in a feedback algorithm that adjusts the feed rate to avoid acetate formation while maintaining a high glucose supply. The feed rate is also restricted to ensure aerobic conditions when the maximum oxygen transfer capacity to the culture is reached.

The feasibility is demonstrated by simulations as well as laboratory-scale experiments with several *E. coli* strains under various operating conditions. Tuning rules that assume a minimum of process specific information are derived and a stability analysis is given.

The feeding strategy relies on good control of the dissolved oxygen concentration. Variations in the oxygen dynamics during a fed-batch cultivation often cause tuning problems when using a controller with fixed parameters. A control approach based on gain scheduling from the stirrer speed is suggested.

9. Honors and Awards

On January 28 **Karl Johan Åström** was given *The King's Medal of the 8th dimension with the ribbon of the order of the Seraphim*, Sweden.

Karl Johan Åström was awarded an *Honorary Doctorate* from the Universidad Nacional de Educación a Distancia, Madrid, Spain, in December 1999.

On December 7 **Tore Hägglund** received an award from *Innovation Cup* for the contribution "The Blend Station." Innovation Cup is sponsored by Skandia and Dagens Industri.

Charlotta Johnsson received a post-doctoral research grant from the Swedish Research Council for Engineering Sciences (TFR) to work at Massachusetts Institute of Technology (MIT), MA, USA.

Mikael Johansson received a post-doctoral research grant from the Swedish Foundation for International Cooperation in Research and Higher Education (STINT) to work at Stanford University, CA, USA.

Johan Eker and **Anton Cervin** were given the *Best Student Paper Award* for their contribution "A Matlab Toolbox for Real-Time and Control Systems Co-Design" at the 6th International Conference on Real-Time Computing Systems and Applications in Hong Kong, P.R. China, in December 1999.

A paper by **Sven Hedlund** and **Anders Rantzer** was ranked 7 among 30 papers nominated for the 1999 IEEE CDC Student Best Paper Award.

Per Hagander, **Tore Hägglund**, **Rolf Johansson**, and **Anders Rantzer** were appointed as Professors in Automatic Control from July 1, 1999.

Bo Bernhardsson was appointed as Professor in Automatic Control from December 1, 1999.

Bo Bernhardsson was nominated as "best teacher of the year" by the electrical engineering students at Lund Institute of Technology.

10. Personnel and Visitors

Personnel

During 1999 the following persons have been employed at the department. The list shows the *status of December 1999* if nothing else is mentioned.

Professors

Karl Johan Åström
Bo Bernhardsson
Per Hagander
Tore Hägglund
Rolf Johansson
Anders Rantzer
Jan Sternby (adjunct 20 %)
Björn Wittenmark

Associate Professors

Karl-Erik Årzén

Guest Professor

Andrey Ghulchak

Research Engineers

Leif Andersson
Anders Blomdell
Rolf Braun

PhD Students

Mats Åkesson

Lennart Andersson *(until December 31)*
Johan Bengtsson *(from April 7)*
Anton Cervin
Lena de Maré *(from August 1)*
Jonas Eborn
Johan Eker
Mattias Grundelius
Magnus Gäfvert
Sven Hedlund
Ari Ingimundarson
Mikael Johansson *(until August 31)*
Charlotta Johnsson
Bo Lincoln *(from January 18)*
Erik Möllerstedt
Hélène Panagopoulos
Mikael Petersson
Anders Robertsson
Rasmus Olsson *(from August 23)*
Lars Malmcolm Pedersen *(until May 31)*
Stefan Solyom *(from August 1)*
Hubertus Tummescheit
Anders Wallén

Secretaries

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

Visiting Scientists

The following researchers have stayed with the department for a couple of days by the least.

Eduardo Quiles *Jan 7–21, 1999*
UPV, Valencia, Spain

Naomi Leonard *Jan 17–23, 1999*
Princeton University, New Jersey, USA

Ricardo Sanz *Feb 8–12, June 7–16, Nov 28 – Dec 5, 1999*
Universidad Politecnica de Madrid, Spain

Ioannis Kanellakopoulos *March 8–16, 1999*
University of California, Los Angeles, USA

Stephen Boyd *March 22–26, 1999*
Stanford University, California, USA

Karl Henrik Johansson *April 6 – June 30, 1999*
Univ. of California at Berkeley, USA

Rogelio Lozano *April 6–8, 1999*
Université de Technologie de Compiegne, France

Joaquin Collado *April 6–8, 1999*
Université de Technologie de Compiegne, France

David Auslander *May 16–23, 1999*
University of California, Berkeley, USA

Tamer Basar *May 19–21, 1999*
Univ of Illinois, Urbana-Champaign, USA

Johan Hedman *May 31 – June 4, 1999*
ABB Corporate Research, Västerås

Dan Block *June 14–17, 1999*
Univ of Illinois, Urbana-Champaign, USA

Qing-Guo Wang *June 20 – July 2, 1999*
National University of Singapore, Singapore

Dan Sorensen *June 24 – 26, 1999*
Rice University, USA

John Lygeros *June 29 – July 1, 1999*
University of California, Berkeley, USA

John Hauser *Aug 26 – Sep 20, 1999*
Caltech, Pasadena, California, USA

Mark Spong *Nov 9–13, 1999*
Univ of Illinois, Urbana-Champaign, USA

John Baras *November 1–2, 1999*
University of Maryland, USA

Michel Gevers *Nov 22–23, 1999*
Universite de Louvain la Neuve, Louvain La Neuve, Belgium

Jan Maciejowski *Nov 24–26, 1999*
Cambridge University, Cambridge, Great Britain

Pedros Albertos *Dec 11 – 14, 1999*
Univ. Politecnica de Valencia, Spain

Walter Schaufelberger *Dec 12 – 14, 1999*
ETH, Zürich, Switzerland

Mogens Blanke *Dec 12 – 14, 1999*
Aalborg University, Denmark

Visiting Students

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

Falko Wagner (P) *Aug 1, 1999 – Jan 31, 2000*
Denmark Technical University (DTU), Lyngby, Denmark

Enrique Pico Marco (S) *Oct 12, 1998 – May 7, 1999*
DISA, U.P. Valencia, Spain

Eduardo Quiles (P) *Jan 4–23, 1999*
Universidad Politecnica de Valencia, Spain

Paolino Tona (P) *Feb 1 – May 15, 1999*
LAG, ENSIEG, Grenoble, France

Olaf Bauer (S) *Feb 1 – June 30, 1999*
Technische Universität Hamburg-Harburg, Germany

Norberto Pires (P) *March 12–23 & July 3 – Aug 15 1999*
University of Coimbra. Portugal

Stefan Solyom *March 13–16, 1999*
University of Timisoara, Romania

Hugo Rodriquez Cortes (P) *June 7–23, 1999*
LSS-Supelec, Gif sur Yvette, France

Michael Grebeck (B) *From July 18, 1999*
Caltech, Pasadena, California

Jorge Goncalves (P) *Aug 25–29, 1999*
Massachusetts Institute of Technology, USA

Simon Hecker, (S) *Aug 30 – Oct 31, 1999*
Technische Universität München, Germany

Leo Siang Kwong (S) *Aug – Dec 1999*
National University of Singapore

Stéphane Velut (S) *From September 13, 1999*
Ecole Nationale Superieure d'Ingenieurs Electriciens de Grenoble, Grenoble, France

Alfredo Loreto (S) *June 30, 1999 – Jan 31, 2000*
La Sapienza, Rome, Italy

Michael Schinkel (S) *Nov 23–27, 1999*
University of Glasgow, Glasgow, Great Britain

Ng Kuan Luen (S) *Sept-Dec 1999*
Imperial College, London, Great Britain

11. Staff Activities

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

Åkesson, Mats

PhD in December 1999, 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 *E. coli* cultivations in a joint project with Pharmacia & Upjohn. He is also engaged in research collaborations with the Department of Biotechnology, Lund University and Active Biotech Research. During 1999, Mats has been a teaching assistant in the courses Process Control and Automatic Control in the engineering curriculum. In December, he defended his PhD dissertation "Probing control of glucose feeding in *Escherichia coli* cultivations."

Andersson, Leif

MSc, Research Engineer since 1970. Leif started at the department with a responsibility for the teaching laboratory. He designed some lab equipment, notably an analog computer. In 1976 he started in ernest with digital computers, and has been responsible for the department computing facilities since then. His professional activities, apart from computer system maintenance, have ranged from computer typesetting (TEX and LATEX) via Real Time Programming to using Java as a tool for writing educational software.

Andersson, Lennart

PhD 1999, graduate student since 1993. His main research interests are in modeling and control of nonlinear systems with uncertainty. In September he presented his thesis "On Simplification of Models with Uncertainty". Lennart Andersson left the department at the end of the year to work for Sigma Exallon Systems AB.

Årzén, Karl-Erik

Associate Professor, PhD (1987), joined the department in 1981. His research interests are real-time systems, Petri nets and Grafcet, fuzzy control, and monitoring and diagnosis. He is project leader for the SSF/ARTES project on integrated control and scheduling, for the NUTEK project on programming languages for real-time control systems, and for the TFR/SSF industrial PhD project on industrial aspects of monitoring and diagnosis. He is also member of the steering committee of LUSERC (Lund Software Engineering Research Centre). During the year he has personally primarily been involved in the EU FAMIMO project on fuzzy control and in the SSF/ARTES project. He has been responsible for and taught the undergraduate course on Real-Time Systems and a graduate course on Discrete Event Systems. He is partly or fully involved in the supervision of five PhD students.

Åström, Karl Johan

Professor at the department since 1965. Department chairman until December 1999. Karl J Åström attended several meetings for the ESF COSY program and he was chief editor of the monograph resulting from the program. He visited Caltech in April and he participated in the UCSB Vistas in Control. In May he visited London to deliver the first Tustin Lecture at the IEE. In July he participated in the IFAC World Congress in Beijing and in August-September he visited Karlsruhe to participate in the European Control Conference. On that occasion he delivered a plenary lecture entitled Automatic Control - the Hidden Technology. In October he participated in a Symposium at MIT to celebrate Professor Mitter. In November he participated in the 50 year celebration of the Science Council of Japan where he delivered an adress. He was an Editor of International Journal of Control and the International Journal of Adaptive Control and Signal Processing. He was reviewer of the National Swedish Project on Technical Foresight.

Bengtsson, Johan

MSc, graduate student since April 1999. He is interested in system identification. Currently, he is working in cooperation with Volvo Technical Development on driver models. During the year Johan was

teaching assistant in the Automatic Control basic course.

Bernhardsson, Bo

Professor, PhD (1992), research associate at the department since 1993. Achieved the degree of Docent in 1998 and Professor in December 1999. Bo is interested in linear system theory, realtime control issues, communication networks, motion control, hybrid control, and applied mathematics in general. He is project leader for the projects on "Analysis of Power Quality" and "Motion Control" described in Section 5. During this year he (co-)supervised the PhD students Cervin, Grundelius, Gäfvert, Möllerstedt, and Lincoln on topics described in Section 5. He also supervised three master theses. During the spring he held the undergraduate course in Nonlinear Control and Servosystems and during the autumn PhD courses in Game Theory and Tools for Control. He was also invitated by the students to give lectures in the introduction programme for the M, I and F programs.

Blomdell, Anders

Research Engineer since 1988. Responsible for the department network and lab computers for teaching and research. Professional interest includes man machine interaction, real-time programming, hardware design, communication protocols, and computer langauges for control engineering. During the previous years, much effort has been spent at enhancing and porting the STORK Real Time Kernel to the various computer platforms used at the department (m680x0, PowerPC, Solaris and WindowsNT). A closely related project is the Modula-2 to C translator used in the real-time research and education at the department.

During this year work has been spent on porting old laboratory software to a modern Linux based platform, thereby increasing both performance and lab design productivity (see also `http://www.control.lth.se/~andersb/linux_in_control/`) compared to the old DOS and WindowsNT solutions.

Braun, Rolf

Research Engineer at the department since 1969. Designs and builds equipment for education and research, and handles hardware maintenance of computers and equipment. He also plans and supervises maintenance and rebuilding of offices and labs.

Cervin, Anton

MSc, graduate student since May 1998. Anton's research interest is real-time systems, and he is involved in the SSF/ARTES project "Integrated Control and Scheduling." During 1999 he has been a teaching assistant in the courses Automatic Control and Real-Time Systems.

Dagnegård, Eva

Webmaster. Joined the department as a secretary in 1975. She works mainly with graphics design and layout, both for paper publishing and for the web. She is also responsible for various activity reports, and handles the contacts with printing offices for dissertations and other publications. During the year she was involved in the preparation of the book *The Åström Symposium on Control* and also in the administration of the symposium itself.

de Maré, Lena

Msc, graduate student since August 1999. She is interested in control of biotechnical processes. She is working together with Mats Åkesson, Stephane Velut and Per Hagander on control of *E. coli* cultivations. She has been a teaching assistant in the undergraduate course in Automatic control, basic course.

Eborn, Jonas

Lic Tech, graduate student since 1995. Interested in computer aided control engineering, physical system modelling and numerical analysis. He is working in the NUTEK programme "Complex Technical Systems" and is also involved in the collaboration with Sydkraft AB. During 1999 he has been teaching assistant in Computer Controlled Systems and the International Project Course in Automatic Control and he has also

supervised a Master's thesis. He is also responsible for the department's seminar schedule.

Eker, Johan

PhD in December 1999. Johan spent most of the year working on his thesis, which is called "Flexible Embedded Control Systems—Design and Implementation." During the year he was also teaching assistant in the courses Computer Controlled Systems and Real-Time Systems.

Gäfvert, Magnus

MSc, graduate student since July 1996. Magnus is interested in topics on distributed control and real-time systems. Current work deals primarily with automotive applications. During the year he has worked on a case study on a truck braking system, provided by Volvo Technological Development within the NUTEK project DICOSMOS. Magnus spends one week per month at Volvo TD in Gothenburg. He has also worked with control of GDI engines, a benchmark problem provided by Siemens Automotive, within the EU Esprit project FAMIMO. His previous work includes modeling, analysis and control of systems with friction. He is also involved in the development of the computer based interactive tools for control education, ICTools. During the year he was a teaching assistant in Computer Controlled Systems and 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 Research & Development AB. He has also been teaching assistant in the Adaptive Control course and supervised one master thesis project.

Ghulchak, Andrey

PhD, guest researcher since September 1998. His current research interest is analysis and design of robust control systems. In particular, he develops methods for robust controller design using convex optimization. In 1999 he has been a teaching assistant in the courses Linear

System I and Linear Quadratic Control for PhD students. He also participated in the IEEE CDC Conference.

Hagander, Per

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 and also the department contactperson for industrial liasons. Per is responsible for the course Computer Controlled Systems.

Since May 1996 he is leading a project with Pharmacia&Upjohn, Process R&D, on multivariable control of genetically engineered *E. coli*. The work is also collaboration with the Department of Biotechnology, Lund University and Active Biotech Research. Here Per works with Mats Åkesson, who defended his PhD-thesis in December 1999.

Hägglund, Tore

Professor, PhD (1984). Has been at the department since 1978 except for four years when he worked for Alfa Laval Automation AB (now ABB Automation Products). He is responsible for two of the basic courses in Automatic Control in the engineering program. His main research interests include process control, PID control, adaptive control, supervision, and detection.

Main research activities during the year have been design of PID and deadtime compensating controllers, and development of supervisory functions for process control. He has also developed a new ratio control structure that is patent pending.

Hedlund, Sven

Lic Tech in September 1999, graduate student since September 1997. His main research interest is analysis and synthesis of hybrid systems and he is involved in the ESPRIT-project H^2C, Heterogeneous Hybrid Control. During 1999, Sven has been a teaching assistant in two undergraduate courses: Nonlinear Control and Servo Systems, and Real-Time Systems.

Ingimundarson, Ari

MSc, graduate student since November 1998. His research interests include process control, automatic tuning and performance monitoring. The main research activities this year have been investigation of automatic tuning of dead-time compensating controllers. Ari has been a teaching assistant in Process Control and Automatic Control, basic course. In April Ari went to Siemens in Toulouse as a part of a group that presented control designs for a car engine benchmark.

Johansson, Mikael

PhD in March, graduate student since 1994. In March 1999 he finished his PhD thesis on the topic "Piecewise Linear Control Systems". Michael then received a postdoctoral scholarship from STINT to spend one year at Stanford University.

Johansson, Rolf

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 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. He has industrial cooperation with ABB Robotics, ABB Corporate Research, and Volvo Technical Development. He is responsible for the two courses System Identification and Adaptive Control in the engineering program. Together with Dr. Måns Magnusson he leads research at the Vestibular Laboratory, Dept. Otorhinolaryngology, Lund University Hospital.

Johnsson, Charlotta

PhD in March 1999, graduate student since August 1993. Her research interests concern control of batch processes. In June 1997 she took her Lic Tech exam and in March 1999 she presented her Ph.D. thesis "A Graphical Langauge for Batch Control". Directly after her PhD dissertation she took some time off with her newborn daughter (born

January 1999). During the fall of 1999, Charlotta developed and taught a course on Automatic Control for Sigma Exallon Systems.

Lincoln, Bo

MSc, graduate student since February 1999. Imported from Linköping Institute of Technology. He has started to work on control problems when wireless networks (such as Bluetooth) are involved. Research is focused on developing current standards so that they are better suited for control purposes. Bo has been a teaching assistant in the basic control course twice; for the mechanical engineers in the spring and for the electrical engineers in the fall.

Mårtensson, Britt-Marie

Secretary at the department since 1974, responsible for the maintenance of the department library, ordering books and journals. She handles the mail every day and office supplies for the department. She also works with scanning and drawing figures with the computer. This year she spent much time with the preparations for the Åström Symposium on Control.

Möllerstedt, Erik

Lic Tech, graduate student since 1994. He is interested in analysis and control of nonlinear and switching systems with applications in power systems. He is working within the Elforsk project *Analysis of Electric Power Quality in Distributions and Loads*. He has been teaching assistant in the undergraduate courses Nonlinear Control and Automatic Control, basic course, and he has supervised two master's projects.

Olsson, Rasmus

MSc, graduate student since August 1999. Rasmus is interested in batch bontrol, and he is part of the CPDC-graduate school. He has also been teaching assistant in the undergraduate course Automatic Control, basic course.

Panagopoulos, Hélène

Msc, graduate student since September 1995. Her research interests concern both theory and applications. The major research area is in the field of PID-controller design. This year she has been teaching two courses in the engineering program: System Identification and the basic course Automatic Control.

Lars Malcolm Pedersen

PhD in May 1999. Has been working at the department from 1992 to 1995 in connection with an industrial research project concerning thickness control for hot rolling mills, which led to his Lic Tech thesis in 1995. During 1997–99 he worked with temperature control of reheat furnaces and in May 1999 he defended his PhD thesis "Modeling and Control of Plate Mill Processes." He is now working in the Plate Mill at The Danish Steel Works Ltd., Frederiksværk, Denmark, where he has been employed since 1991.

Mikael Petersson

PhD student, joined the department in 1997. Petersson is an industrial PhD-student employed by ABB Corporate Research. He has been active in the control engineering area within the ABB group since 1994. His research interests include control performance monitoring and diagnostics of industrial processes, and applying and evaluating advanced theory in this area. The recent activities include evaluating various control performance measures, and developing tools for control structure selection. The main application area for the research has been limited to the process industry, namely the pulp and paper process.

Rantzer, Anders

Professor, PhD. Joined the department in 1993 after a PhD at KTH 1991 and a postdoc position at IMA, University of Minnesota. Anders has broad interests in modeling, analysis and design of control systems. In particular, he develops methods for treatment of uncertainty and nonlinearities using convex optimization.

Anders is responsible for the basic course in Automatic Control for electrical engineers. He serves as associate editor of several journals. In July 1999 he organized an invited session at the IFAC World Congress in Beijing and he edited the proceedings of the Åström Symposium on control. He gave invited presentations at several workshops and conferences.

Robertsson, Anders

PhD 1999, graduate student since 1993. His main interest is in nonlinear control and robotics. Currently he is working on sensor-data integration and force control of industrial robots under a NUTEK project in collaboration with ABB Robotics. In December he presented his thesis "On Observer-Based Control of Nonlinear Systems."

Schildt, Eva

Secretary at the Department since 1970. Eva is mainly responsible for the financial transactions of the department, such as bookkeeping and reporting to our sponsors. She handles various personnel administration and takes care of the administration concerning the many visitors at the department. During this year she was one of the organizers of the Åström Symposium on Control, August 27–28.

Solyom, Stefan

MSc, graduate student since August 1999. His current research interest is model predictive control. During the fall he was teaching assistant in the Adaptive Control course, in the engineering curriculum.

Sternby, Jan

Professor, adjuncted part-time (20%). He is also working in the Therapy Research group at Gambro AB in Lund. Jan Sternbys research interests include anti-windup methods, control of systems with periodic disturbances, adaptive control and all aspects of modeling in dialysis. He has developed a project course which is part of the Master's program at the department.

Tummescheit, Hubertus

MSc, graduate student since 1996, joined the department in July 1998. Interested in physical system modelling, modelling language design and numerical analysis. He is working in the NUTEK programme "Complex Technical Systems" and is also involved in the collaboration with Sydkraft AB. Since 1997 he is a member of the Modelica Design Group and has actively been involved with the development of the Modelica language. During 1999 he has been teaching assistant in two basic control courses. He has also supervised a Master's thesis on Modelling of Two-Phase Flows with Modelica.

Tuszynski, Agneta

Secretary at the department since 1981. She is responsible for registration of the student's course entries and exam results, and supervises the invoice payments from the department. She also works with word processing in LaTeX, helping colleagues with writing letters, articles, and reports. This year she was involved in the preparations for the Åström Symposium on Control.

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 project "Autonomous Control." During the year Anders has been teaching assistant in Computer-Controlled Systems and the basic course in 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 "Center for Chemical Process Design and Control." 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: External opponent on the licentiate thesis by Mr Kristian Sandström Dept of Machine Design, KTH, April 8. Opponent on the PhD thesis of Mr. Roozbeh Izadi-Zamanabadi, Dept of Control Engineering, Aalborg University, Denmark, September 22. Member of the examination board of the PhD thesis of Mr Magnus Larsson, Dept of Automatic Control, Linköping University, December 3.

Bo Bernhardsson: Member of examination committees for the PhD students Olof Lindgärde at the Department of Automatic Control, Chalmers, in October, and Anders Sjö in Numerical Analysis, Lund University, in December.

Per Hagander: Member of the examination committee for Mattias Nyberg's PhD dissertation, Linköping University, Sweden, June 1999.

Tore Hägglund: External examiner for the PhD thesis "Towards autonomous control of HVAC systems" by Per Brath, Aalborg University, Denmark.

Anders Rantzer Member of the examination board for the PhD thesis "Analysis and Design of Hybrid Systems" by Stefan Pettersson, Chalmers, Gothenburg, June 10

Björn Wittenmark: Member of examination board for the dissertation by Maria Kihl at the Department of Communication Systems, LTH, May 3, 1999.

Board Member

Karl-Erik Årzén: Member of the Board of SSF ARTES program from December.

Per Hagander: Vice-chairman of the Board of Engineering Physics program at Lund Institute of Technology. Member of the Computer Group of FED, Lund Institute of Technology.

Tore Hägglund: Member of the Education Board of Computer Science and Technology, and deputy member of the Appointments Board II, both at Lund Institute of Technology.

Anders Rantzer: Member of expert committee for applied mathematics within the Swedish Research Council for Engineering Sciences.

Hubertus Tummescheit: Member of the Modelica Design Group.

Björn Wittenmark: Deputy Dean and board member of Lund Institute of Technology. Board member of Lunds Universitets Utvecklings Aktiebolag (Lund University Development Limited), of Lunds Datacentral, LDC, (Lund University Computing Center), and of Chematur AB. Swedish representative of European Union Control Association (EUCA) Council. Chairman of the committee for IFAC Control Engineering Practice Price.

Book and Journal Editor

Karl-Erik Årzén: Advisory Editor for Engineering Applications of Artificial Intelligence.

Tore Hägglund: Associate editor for Control Engineering Practice.

Rolf Johansson is associate editor of the IEEE CSS Conference Editorial Board.

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

Björn Wittenmark: Optimal Control Applications & Methods, Journal of Forecasting, and International Journal of Adaptive Control and Signal Processing

Advisory Committees and Working Groups

Karl Johan Åström: Member of research committee FIME at Lund Institute of Technology. Member of the research advisory councils for the LIDS Laboratory at MIT and for the Center for Systems Science at University of Maryland. Member of an expert group for evaluation

the Swedish Program for Vehichle Research (Fordonstekniska Forskningsprogrammet). Chairman of the IFAC Award Committee for the Quazza and Nichols medals and the ESF COSY (Control of Complex Systems) program. Member of the Medal Committee and the Committee for the Chester Carlsson Prize of IVA.

Per Hagander: Member of IFAC Technical Committee on Biomedical Engineering and Control. member of the IEEE Technical Committee on Robust Control

Björn Wittenmark: Member of evaluation board for professorship in automatic control at the Institute for Automation at DTU. Member of evaluation board for senior lecture in automatic control at KTH. Member of working group for planning of strategic research at Lund University.

Member of International Program Committee (IPC)

Karl-Erik Årzén: Member of IPC for EuroMicro 99, York, UK. Member of IPC for EuroMicro 2000, Stockholm, Sweden. Member of IPC for ADPM 2000, Germany.

Tore Hägglund: Member of the IPC for the IFAC Workshop on Digital Control—Past, present and future of PID Control, Terrassa, Spain.

Anders Rantzer Member of IPC for Hybrid Systems: Computation and Control—Third International Workshop, March 2000, Pittsburgh, USA. Member of IPC Control 2000, Cambridge, UK.

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, 8 book contributions, 16 journal papers, 45 conference contributions, and 5 conference abstracts have been published this year.

Books and Proceedings

Tan, K. K., Q. G Wang, C. C. Hang, and T. Hägglund: *Advances in PID control*. Advances in Industrial Control. Springer Verlag, 1999.

Wittenmark, Björn, and Anders Rantzer, Eds.: *The Åström Symposium on Control*, Lund, Sweden, 1999. Studentlitteratur. ISBN 91-44-01245-4.

Book Contributions

Årzén, Karl-Erik, and Mikael Johansson: "Fuzzy control: From heuristic PID to optimization-based nonlinear control." In Verbruggen and Babuska, Eds., *Fuzzy Logic Control: Advances in Applications*, pp. 37–61. World Scientific Publishing, 1999.

Årzén, Karl-Erik, Mikael Johansson, and R. Babuska: "Fuzzy control versus conventional control." In Verbruggen *et al.*, Eds., *Fuzzy Algorithms for Control*, pp. 59–82. Kluwer Academic Publishers, 1999.

Åström, Karl Johan: "Automatic control—The hidden technology." In Frank, Ed., *Advances in Control—Highlights of the ECC '99*, pp. 1–29, London, UK, 1999. Springer.

Åström, Karl Johan: "Hybrid control of inverted pendulums." In Yamamoto and Hara, Eds., *Learning, Control, and Hybrid Systems*, pp. 150–163. Springer, 1999.

Åström, Karl Johan, and Tore Hägglund: "PID control." In Levine, Ed., *Control System Fundamentals*, pp. 198–209. CRC Press, 1999.

Jönsson, Ulf, and Anders Rantzer: "Optimization of integral quadratic constraints." In El Ghaoui and Niculescu, Eds., *Advances in Linear Matrix Inequality Methods in Control*. SIAM, December 1999. ISBN 0-89871-438-9.

Lefeber, E., A. Robertsson, and H. Nijmeijer: "Linear controllers for tracking chained-form systems." In Aeyels *et al.*, Eds., *Stability and Stabilization of Nonlinear Systems*, vol. 246 of *Lecture Notes in Control and Information Sciences*, pp. 183–197. Springer-Verlag, Heidelberg, 1999. ISBN 1-85233-638-2.

Rantzer, Anders: "To estimate the L_2-gain of two dynamic systems." In Blondel *et al.*, Eds., *Open Problems in Mathematical Systems and Control Theory*, chapter 36. Springer, 1999.

Journal Papers

Åkesson, Mats, Per Hagander, and Jan Peter Axelsson: "A probing feeding strategy for *Escherichia coli* cultures." *Biotechnology Techniques*, **13**, pp. 523–528, 1999.

Åkesson, M., E. Nordberg Karlsson, P. Hagander, J. P. Axelsson, and A. Tocaj: "On-line detection of acetate formation in *escherichia coli* cultures using dissolved oxygen responses to feed transients." *Biotechnology and Bioengineering*, **64**, pp. 590–598, 1999.

Andersson, Lennart, and Anders Rantzer: "Frequency-dependent error bounds for uncertain linear models." *IEEE Transactions on Automatic Control*, **44:11**, pp. 2094–2098, 1999.

Andersson, Lennart, Anders Rantzer, and Carolyn Beck: "Model comparison and simplification." *International Journal of Robust and Nonlinear Control*, **9:3**, pp. 157–181, March 1999.

Åström, Karl Johan: "Moving average and self-tuning control." *Int. J. Adapt. Control Signal Process*, **13:6**, pp. 451–467, 1999.

Chou, C. T., M. Verhaegen, and R. Johansson: "Continuous-time identification of SISO systems using Laguerre functions." *IEEE Transactions on Signal Processing*, **47**, February, pp. 349–362, February 1999.

Hägglund, Tore: "Automatic detection of sluggish control loops." *Control Engineering Practice*, **7**, pp. 1505–1511, 1999.

Hansson, Anders, and Per Hagander: "How to decompose semi-definite discrete-time algebraic Riccati equations." *European Journal of Control*, **5:2**, pp. 245–260, 1999.

Holm, M., R. Johansson, B. Smideberg, C. Lührs, and S. B. Olsson: "Effect of cardiac exposure by median sternotomy on atrial fibrillaton cycle length." *Europace*, **1**, pp. 248–257, 1999.

Johansson, Karl Henrik, and Anders Rantzer: "Decentralized control of sequentially minimum phase systems." *IEEE Transactions on Automatic Control*, **44:10**, pp. 1909–1913, 1999.

Johansson, Karl Henrik, Anders Rantzer, and Karl Johan Åström: "Fast switches in relay feedback systems." *Automatica*, **35:4**, pp. 539–552, 1999.

Johansson, Mikael, Anders Rantzer, and Karl-Erik Årzén: "Piecewise quadratic stability of fuzzy systems." *IEEE Transactions on Fuzzy Systems*, **07:06**, pp. 713–722, December 1999.

Johansson, R., M. Verhaegen, and C. T. Chou: "Stochastic theory of continuous-time state-space identification." *IEEE Transactions on Signal Processing*, **47**, January, pp. 41–51, January 1999.

Lindoff, B., J. Holst, and B. Wittenmark: "Analysis of approximations to dual control." *Int. J. Adaptive Control and Signal Processing*, **13**, pp. 593–620, 1999.

Nilsson, Klas, and Rolf Johansson: "Integrated architecture for industrial robot programming and control." *J. Robotics and Autonomous Systems*, **29**, pp. 205–226, 1999.

Pedersen, Lars Malcolm, and Björn Wittenmark: "Development of advanced furnace control algorithm." *Steel Technology International*, pp. 149–152, 1999.

Conference Papers

Åkesson, Mats, and Per Hagander: "A gain-scheduling approach for control of dissolved oxygen in stirred bioreactors." In Chen *et al.*, Eds., *Preprints 14th World Congress of IFAC*, vol. O, pp. 505–510, Beijing, P.R. China, July 1999.

Andersson, Lennart, and Anders Rantzer: "Robustness of equilibria in nonlinear systems." In *Preprints 14th World Congress of IFAC*, vol. E, pp. 129–134, Beijing, P.R. China, 1999.

Årzén, Karl-Erik: "Graphical languages for intelligent process control applications." In *Proc. of IEEE Conf. on Intelligent Control*, Boston, Massachusetts, 1999.

Årzén, Karl-Erik: "A simple event-based PID controller." In *Preprints 14th World Congress of IFAC*, Beijing, P.R. China, 1999.

Åström, Karl Johan, and Bo Bernhardsson: "Comparison of periodic and event based sampling for first-order stochastic systems." In *Preprints 14th World Congress of IFAC*, vol. J, pp. 301–306, Beijing, P.R. China, July 1999.

Åström, Karl Johan, K. Furuta, M. Iwashiro, and T. Hoshino: "Energy based strategies for swinging up a double pendulum." In *Preprints 14th World Congress of IFAC*, vol. M, pp. 283–288, Beijing, P.R. China, July 1999.

Bernhardsson, Bo, Karl Henrik Johansson, and Jörgen Malmborg: "Some properties of switched systems." In *Preprints 14th World Congress of IFAC*, vol. J, pp. 85–90, Beijing, P.R. China, 1999.

Cervin, Anton: "Improved scheduling of control tasks." In *Proceedings of the 11th Euromicro Conference on Real-Time Systems*, pp. 4–10, York, UK, June 1999.

Collado, J., R. Lozano, and R. Johansson: "On Kalman-Yakubovich-Popov lemma for stabilizable systems." In *Proceedings 38th IEEE Conference on Decision and Control (CDC'99)*, Phoenix, Arizona, December 1999.

Dai, Liankui, and Karl Johan Åström: "Dynamic matrix control of a quadruple-tank process." In *Preprints 14th World Congress of IFAC*, vol. N, pp. 295–300, Beijing, P.R. China, July 1999.

Eborn, Jonas, Hélène Panagopoulos, and Karl Johan Åström: "Robust PID control of steam generator water level." In *Preprints 14th World Congress of IFAC*, vol. G, pp. 461–464, Beijing, P.R. China, July 1999.

Eborn, Jonas, Hubertus Tummescheit, and Karl Johan Åström: "Physical system modeling with Modelica." In *14th World Congress of IFAC*, vol. N. IFAC, July 1999.

Eker, J.: "A tool for interactive development of embedded control systems." In *Preprints 14th World Congress of IFAC*, Beijing, P.R. China, 1999.

Eker, Johan, and Anton Cervin: "A Matlab toolbox for real-time and control systems co-design." In *Proceedings of the 6th International Conference on Real-Time Computing Systems and Applications*, pp. 320–327, Hong Kong, P.R. China, December 1999.

Eker, Johan, and Jörgen Malmborg: "Design and implementation of a hybrid control strategy." *IEEE Control Systems Magazine*, **19:4**, August 1999.

Gäfvert, Magnus: "Dynamic model based friction compensation on the Furuta pendulum." In *Proceedings 1999 IEEE Int. Conf. Control Applications and the Symp. Computer Aided Control Systems Design (CCA'99&CACSD'99)*, Kohala Coast, Hawaii, August 1999.

Gäfvert, Magnus, Joakim Svensson, and Karl Johan Åström: "Friction and friction compensation in the Furuta pendulum." In *Proc. 5th European Control Conference (ECC'99)*, Karlsruhe, Germany, 1999.

Ghulchak, Andrey, and Anders Rantzer: "Robust controller design via linear programming." In *Proceedings 38th IEEE Conference on Decision and Control (CDC'99)*, Phoenix, Arizona, December 1999.

Grundelius, Mattias, and Bo Bernhardsson: "Control of liquid slosh in an industrial packaging machine." In *Proceedings 1999 IEEE Int. Conf. Control Applications and the Symp. Computer Aided Control Systems Design (CCA'99&CACSD'99)*, Kohala Coast, Hawaii, August 1999.

Grundelius, Mattias, and Bo Bernhardsson: "Motion control of open containers with slosh constraints." In *Preprints 14th World Congress of IFAC*, vol. L, pp. 487–492, Beijing, P.R. China, July 1999.

Haverkamp, B. R. J., M. Verhaegen, C. T. Chou, and R. Johansson: "Tuning of the continuous-time Kalman filter from sampled data." In *Proc. American Control Conference (ACC'99)*, pp. 3895–3899, San Diego, California, June 1999.

Hedlund, Sven, and Mikael Johansson: "A toolbox for computational analysis of piecewise linear systems." In *Proceedings of European Control Conference*, Karlsruhe, Germany, 1999.

Hedlund, Sven, and Anders Rantzer: "Optimal control of hybrid systems." In *Proceedings 38th IEEE Conference on Decision and Control(CDC'99)*, Phoenix, Arizona, December 1999. Invited paper.

Johansson, Mikael, Andrey Ghulchak, and Anders Rantzer: "Improving efficiency in the computation of piecewise quadratic Lyapunov functions." In *Proceeedings of the 7th Mediterranean Conference in Control and Automation*, Haifa, Israel, June 1999.

Johansson, R., , M. Verhaegen, B. R. J. Haverkamp, and C. T. Chou: "Correlation methods of continuous-time state-space model identification." In *Proc. 5th European Control Conference (ECC'99)*, Karlsruhe, Germany, September 1999. Invited paper.

Johansson, R., M. Holm, S. B. Olsson, and J. Brandt: "System identification of atrial activation during chronic atrial fibrillation in man." In *Preprints 14th World Congress of IFAC*, vol. I, pp. 91–96, Beijing, P.R. China, July 1999. Invited paper.

Johansson, Rolf, and Anders Robertsson: "Extension of the Yakubovich-Kalman-Popov lemma for stability analysis of dynamic output feedback systems." In *Preprints 14th World Congress of IFAC*, vol. F, pp. 393–398. IFAC, July 1999. Beijing, China.

Johansson, Rolf, Anders Robertsson, and R. Lozano-Leal: "Stability analysis of adaptive output feedback control." In *Proceedings 38th IEEE Conference on Decision and Control (CDC'99)*, pp. 3796–3801, Phoenix, Arizona, December 1999.

Johnsson, Charlotta, and Karl-Erik Årzén: "Grafchart and batch recipe structures." In *Proc. Interphex '99*, New York, April 1999.

Johnsson, Charlotta, and Karl-Erik Årzén: "Grafchart and Grafcet: A comparison between two graphical languages aimed for sequential control applications." In *Preprints 14th World Congress of IFAC*, vol. A, pp. 19–24, Beijing, P.R. China, July 1999.

Langer, Jochen, Ioan Landau, and Anders Rantzer: "Pole placement with sensitivity function shaping for a set of models via convex optimization." In *Proceedings 38th IEEE Conference on Decision and Control (CDC'99)*, Phoenix, Arizona, December 1999.

Lefeber, E., A. Robertsson, and H. Nijmeijer: "Output feedback tracking of nonholonomic systems in chained form." In *Proc. 5th European Control Conference (ECC'99)*, Karlsruhe, Germany, 1999. Paper 772 (AP-4).

Lefeber, E., A. Robertsson, and H. Nijmeijer: "Output feedback tracking of nonholonomic systems in chained form." In *18th Benelux meeting on System and Control*, Houthalen-Helchteren, Belgium, 1999.

Möllerstedt, Erik, Bo Bernhardsson, and Sven Erik Mattsson: "A load model structure for analysis and control of electric distribution network." In *Preprints 14th World Congress of IFAC*, vol. L, pp. 493–498, Beijing, P.R. China, 1999.

Öhman, Martin, and Anders Rantzer: "Trajectory-based model reduction of nonlinear systems." In *Preprints 14th World Congress of IFAC*, vol. H, pp. 67–72, Beijing, P.R. China, 1999.

Panagopoulos, H., and K. J. Åström: "PID control design and H_∞ loop shaping design of PI controllers based on non-convex optimization." In *Proceedings 1999 IEEE Int. Conf. Control Applications and the Symp. Computer Aided Control Systems Design (CCA'99&CACSD'99)*, Kohala Coast, Hawaii, August 1999.

Panagopoulos, H., K. J. Åström, and T. Hägglund: "Design of PID controllers based on constrained optimization." In *Proc. 1999 American Control Conference (ACC'99)*, San Diego, California, June 1999. Invited paper.

Persson, M., F. Botling, E. Hesslow, and R. Johansson: "Stop-and-go controller for adaptive cruise control." In *Proceedings 1999 IEEE Int. Conf. Control Applications and the Symp. Computer Aided Control Systems Design (CCA'99&CACSD'99)*, pp. CCA–1692, Kohala Coast, Hawaii, 1999.

Rantzer, Anders: "Dynamic programming via convex optimization." In *Preprints 14th World Congress of IFAC*, vol. D, pp. 491–496, Beijing, P.R. China, 1999.

Rantzer, Anders: "A simple performance criterion for anti-windup compensators." In *Proc. 5th European Control Conference (ECC'99)*, Karlsruhe, Germany, 1999.

Robertsson, Anders, and Rolf Johansson: "Observer backstepping for a class of nonminimum-phase systems." In *Proceedings 38th IEEE Conference on Decision and Control (CDC'99)*, pp. 4866–4871, Phoenix, Arizona, December 1999.

Tona, P., J. Eker, and M. M'Saad: "PALSIMART: a new framework for computer aided rapid prototyping of advanced control systems." In *Proceedings of the European Control Conference*, Karlsruhe, Germany, 1999.

Valera, A., A. Robertsson, K. Nilsson, and R. Johansson: "Interactive online evaluation of robot motion control." In *Proceedings 1999 IEEE Int. Conf. Control Applications and the Symp. Computer Aided Control Systems Design (CCA'99&CACSD'99)*, pp. CCA–1039–1044, Kohala Coast, Hawaii, August 1999.

Wallén, Anders: "A tool for rapid system identification." In *Proceedings 1999 IEEE Int. Conf. Control Applications and the Symp. Computer Aided Control Systems Design (CCA'99&CACSD'99)*, Kohala Coast, Hawaii, August 1999.

Conference Abstracts

Åkesson, Mats, Per Hagander, and Jan Peter Axelsson: "A probing feeding strategy for *E. coli* cultivations." In *Abstract book of 217th ACS National Meeting*, Anaheim, California, March 1999.

Åkesson, Mats, Per Hagander, and Jan Peter Axelsson: "A probing feeding strategy for recombinant *E. coli* cultivations." In *9th European Congress on Biotechnology*, Brussels, Belgium, July 1999. Invited lecture.

Bernhardsson, Bo: "Control of realtime system with unknown timing behavior." In *Workshop on Approximation and Robustness in Systems and Control*, Hong Kong, P.R. China, July 1999.

Cervin, Anton: "Improved scheduling of control tasks." In *ARTES Real-Time Graduate Student Conference*, pp. 104–114, Västerås, Sweden, May 1999.

Eker, Johan, and Anton Cervin: "A Matlab toolbox for real-time and control systems co-design." In *Proceedings of SNART'99—Swedish Conference on Real-Time Systems*, pp. 55–60, Linköping, Sweden, August 1999.

13. Reports

Durint this year 7 PhD theses and 1 Lic Tech thesis have been published. The abstracts are presented in Chapter 8. Also 23 master theses and 7 internal reports have been completed.

Dissertations

Åkesson, Mats: *Probing Control of Glucose Feeding in Escherichia coli Cultivations*. PhD thesis ISRN LUTFD2/TFRT--1057--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 1999.

Andersson, Lennart: *On Simplification of Models with Uncertainty*. PhD thesis ISRN LUTFD2/TFRT--1054--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1999.

Eker, Johan: *Flexible Embedded Control Systems. Design and Implementation*. PhD thesis ISRN LUTFD2/TFRT--1055--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 1999.

Hedlund, Sven: *Computational Methods for Hybrid Systems*. Lic Tech thesis ISRN LUTFD2/TFRT--3225--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1999.

Johansson, Mikael: *Piecewise Linear Control Systems*. PhD thesis ISRN LUTFD2/TFRT--1052--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 1999.

Johnsson, Charlotta: *A Graphical Language for Batch Control*. PhD thesis ISRN LUTFD2/TFRT--1051--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 1999.

Pedersen, Lars Malcolm: *Modeling and Control of Plate Mill Processes*. PhD thesis ISRN LUTFD2/TFRT--1053--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 1999.

Robertsson, Anders: *On Observer-Based Control of Nonlinear Systems*. PhD thesis ISRN LUTFD2/TFRT--1056--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 1999.

Master Theses

Almers, Martin: "Analog and digital signal processing in an optical application." Master thesis ISRN LUTFD2/TFRT--5623--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, August 1999.

Bauer, Olof: "Modelling of two-phase flows with Modelica." Master thesis ISRN LUTFD2/TFRT--5629--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 1999.

Bengtsson, Johan, and Anders Ahlstrand: "A robot playing scrabble using visual feedback." Master thesis ISRN LUTFD2/TFRT--5616--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, April 1999.

Cordes, Mikael, and Andreas Johansson: "Synchronization in ADSL modems." Master thesis ISRN LUTFD2/TFRT--5612--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 1998.

Gustafsson, Lars, and Mikael Olsson: "Robust on-line estimation." Master thesis ISRN LUTFD2/TFRT--5633--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 1999.

Hedin, Anders: "New control concept for Haldex limited slip coupling." Master thesis ISRN LUTFD2/TFRT--5611--SE, Department

of Automatic Control, Lund Institute of Technology, Lund, Sweden, February 1999.

Henriksson, Mattias: "Modellering av glukos- och acetat-metabolism i *escherichia coli*," (Modeling of glucose and acetate metabolism in *escherichia coli*). Master thesis ISRN LUTFD2/TFRT--5613--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1999.

Jönsson, Bengt, and Torkel Lundgren: "Pressure control of Haldex limited slip coupling." Master thesis ISRN LUTFD2/TFRT--5624--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, August 1999.

Kvistholm, Joakim: "Neural networks in extremal seeking control." Master thesis ISRN LUTFD2/TFRT--5615--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, April 1999.

Lannegren, Henrik: "Motion control with slosh suppression." Master thesis ISRN LUTFD2/TFRT--5634--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 1999.

Lembke, Martin: "Identification of respiratory mechanics during mechanical ventilation." Master thesis ISRN LUTFD2/TFRT--5620--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, June 1999.

Lundqvist, Niclas: "Modellering av ett plattvärmeväxlarsystem med reglering på ång- och sekundärsidan," (Modelling of a plate exchanger system with control on both the steam and secondary side). Master thesis ISRN LUTFD2/TFRT--5628--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, August 1999.

Nilsson, Martin: "An H_∞ centering controller for single-wheel drive equipped boogie." Master thesis ISRN LUTFD2/TFRT--5631--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 1999.

Nilsson-Stig, Anders, and Henrik Perbeck: "Equalization of co-channel interference in future mobile communication systems." Master thesis ISRN LUTFD2/TFRT--5610--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, January 1999.

Norberg, Albert: "Kappa Tuning—improved relay auto-tuning for PID controllers." Master thesis ISRN LUTFD2/TFRT--5621--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, June 1999.

Olsson, Pär: "Automatisk övervakning och diagnos av pappersmaskin," (Automatic sypervision and diagnosis of a paper machine). Master thesis ISRN LUTFD2/TFRT--5632--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 1999.

Örsmark, Ola, and Magnus Bengtsson: "Modeling and control of an hydraulic actuator." Master thesis ISRN LUTFD2/TFRT--5614--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 1999.

Petef, Andrej, and Jimmie Landerman: "Digital loudspeaker equalization." Master thesis ISRN LUTFD2/TFRT--5618--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 1999.

Pico Marco, Enrique: "Robust control of a flexible servo with parametric uncertainty." Master thesis ISRN LUTFD2/TFRT--5617--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 1999.

Rosdahl, Fredrik: "Adaptive rejection of multiple sinusoids in measurement signals." Master thesis ISRN LUTFD2/TFRT--5619--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 1999.

Sandberg, Daniel: "System identification for modeling of stock market index." Master thesis ISRN LUTFD2/TFRT--5630--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 1999.

Sandberg, Henrik: "Nonlinear modeling of locomotive propulsion system and control." Master thesis ISRN LUTFD2/TFRT--5625--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, August 1999.

Steineck, Adam: "Non-linear control of a bouncing ball." Master thesis ISRN LUTFD2/TFRT--5622--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, August 1999.

Ungerbrandt, Simon: "Product test bench based on real-time simulation." Master thesis ISRN LUTFD2/TFRT--5627--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1999.

Velut, Stéphane: "Control of substrate feeding in *Escherichia coli* cultures." Master thesis ISRN LUTFD2/TFRT--5626--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, June 1999.

Other Reports

Årzén, K.-E., B. Bernhardsson, J. Eker, A. Cervin, K. Nilsson, P. Persson, and L. Sha: "Integrated control and scheduling." Report ISRN LUTFD2/TFRT--7586--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, August 1999.

Dagnegård, Eva, and Björn Wittenmark: "Automatic Control 1998. Activity report." Report ISRN LUTFD2/TFRT--4026--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 1999.

Gäfvert, Magnus, Martin Sanfridsson, and Vilgot Claesson: "Truck model for yaw and roll dynamics control." Report ISRN LUTFD2/TFRT--7588--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, 1999.

Hedlund, Sven, and Mikael Johansson: "PWLTool, a Matlab toolbox for piecewise linear system." Report ISRN LUTFD2/TFRT--7582--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 1999.

Hägglund, Tore: "The blend station." Report ISRN LUTFD2/TFRT--7583--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 1999.

Johansson, Karl Henrik, and Tore Hägglund: "Control structure design in process control systems." Report ISRN LUTFD2/TFRT--7585--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1999.

Johansson, Mikael, and Bo Bernhardsson: "Research abatracts 1999—PhD projects in automatic cotrol." Report ISRN LUTFD2/TFRT--7584--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, June 1999.

Åkesson, Johan: "Safe reference following on the inverted pendelum." Report ISRN LUTFD2/TFRT--7587--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, August 1999.

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:

- Linköpings Universitetsbibliotek, Svensktrycket, SE-581 83 Linköping
- UB 2, Svenska Tryckavdelningen, Box 1010, SE-221 03 Lund
- Stockholms Universitetsbibliotek, Svenska Tryckavdelningen, SE-106 91 Stockholm
- Kungliga Biblioteket, Box 5039, SE-102 41 Stockholm
- Umeå Universitetsbibliotek, Box 718, SE-901 10 Umeå
- Uppsala Universitetsbibliotek, Box 510, SE-751 20 Uppsala

The reports in the 1000- and 3000-series may be ordered from the Department. See addresses on page 4. Please be certain to specify both the report number and report title.

There is a copying and handling charge of between 300 and 500 SEK for each document. Invoice will be sent together with the ordered report(s).

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

Control of Substrate Feeding in Escherichia coli *Cultures,* Invited lecture. Workshop on Metabolism and Control of Bioprocesses, Swedish Institute for Food and Biotechnology, Lund, Sweden, February 4.

A Probing Feeding Strategy for Recombinant E. coli *Cultivations,* Invited lecture. The 9th European Congress on Biotechnology, Brussels, Belgium, July 15.

Probing Control of Glucose Feeding in Escherichia coli *Cultivations,* NUTEK Program workshop, Ystad, Sweden, November 16.

A Probing Feeding Strategy for E. coli *Cultures,* Danisco Biotechnology A/S, Copenhagen, Denmark, November 23.

Andersson, Lennart

Simplification of Models with Uncertainty, Caltech, Pasadena, November 10.

Simplification of Models with Uncertainty, University of Illinois, Urbana-Champaign, November 17.

Årzén, Karl-Erik

Demystifying Fuzzy Control and Neural Networks, SIK-meeting, Lund, Sweden, February 4.

Fuzzy Control: From heuristic PID to optimization-based nonlinear control, Fuzzy Control Summer School, Delft, The Netherlands, April 20.

Grafchart and Grafcet: A comparison between two graphical languages aimed for sequential control application, IFAC World Congress, Beijing, P.R. China, July 5.

A simple event-based PID controller, IFAC World Congress, Beijing, P.R. China, July 8.

Simple control laws and mode-switching strategies for direct injection engines, Linköping University, Sweden, August 26.

Graphical Languages for Intelligent Process Control Applications, IEEE Conf. on Intelligent Control, Boston Massachusetts, September 17.

Åström, Karl Johan

Friction - A Control Perspective, UCSB April 6

Friction Models and Friction Compensation, Caltech April 14

Digital Control - A Perspective, The First Tustin Lecture IEE London May 12 Invited lecture

Friction Models and Friction Compensation, Cambridge May 14

Comparison of Periodic and Event Based Sampling, IFAC World Congress Beijing

Automatic Control - The Hidden Technology, Invited Plenary Lecture ECC August 31 Karlsruhe

Model Uncertainty and Robust Control Design, COSY Meeting Valencia September 16

Friction Models and Friction Compensation, MIT October 14

Riemann and Lebesgue Sampling, MIT Seminar in the Honor of Prof Sanjoy Mitter October 15

Friction Models and Friction Compensation, Tokyo Institute of Technology, Tokyo October 29,

Bernhardsson, Bo

Control of Realtime Systems Random Time Delays, Lecture at Sigma Exallon Systems, Malmö. January 26.

Control of Realtime System With Unknown Timing Behavior, Workshop on Approximation and Robustness in Systems and Control, HongKong, July 1.

A Load Model Structure for Analysis and Control of Electric Distribution Network, IFAC World Congress in Bejing, P.R. China, July 6.

Cervin, Anton

Improved Scheduling of Control Tasks, ARTES Real-Time Graduate Student Conference, Västerås, Sweden, May 10.

Improved Scheduling of Control Tasks, 11th Euromicro Conference on Real-Time Systems, York, UK, June 9.

A Matlab Toolbox for Real-Time and Control Systems Co-Design, SNART'99—Swedish Conference on Real-Time Systems, Linköping, Sweden, August 25.

Integrated Control and Scheduling, Invited seminar at DICOSMOS meeting, Gothenburg, Sweden, September 9.

Eborn, Jonas

Robust PID Control of Steam Generator Water Level, Seminar. IFAC World Congress, Beijing, P.R. China. July 9.

Gäfvert, Magnus

Friction and Friction Compensation in the Furuta Pendulum, European Control Conference ECC'99, Karlsruhe, Germany, September 2.

Dynamic Model Based Friction Compensation on the Furuta Pendulum, IEEE International Conference on Control Applications, Hawaii, August 24.

Grundelius, Mattias

Motion Control of Open Containers with Slosh Constraints, Invited lecture, Tetra Rex Inc., Buffalo Grove, IL, January 25.

Motion Control of Open Containers with Slosh Constraints, University of Illinois at Urbana-Champaign, Urbana-Champaign, IL, January 28.

Motion Control of Fluid Containers, Mechatronics day, Lund Institute of Technology, Lund, Sweden, May 19.

Motion Control of Open Containers with slosh Constraints, 14th IFAC World Congress, Beijing, P.R. China, July 9.

Control of Liquid Slosh in an Industrial Packaging Machine, 1999 IEEE Conference on Control Applications, Kohala Coast, HW, August 25.

Hagander, Per

Control of Biotechnical Processes, Invited lecture. Workshop on Metabolism and Control of Bioprocesses, Swedish Institute for Food and Biotechnology, Lund, Sweden. February 4, 1999.

Hedlund, Sven

Convex Dynamic Programming for Hybrid Systems, California Institute of Technology, Pasadena, USA, December 13.

Convex Dynamic Programming for Hybrid Systems, University of California Santa Barbara, Santa Barbara, USA, December 14.

Hägglund, Tore

Methods for supervision and detection, Invited lecture. Stora Enso Hylte AB, Hylte, Sweden, January 22.

Process Control in Practice, Industrial course. Sundsvall, Sweden, February 3–4.

Control of HVDC systems, Invited lecture. ABB Power Systems, Ludvika, Sweden, February 12.

Process Control in Practice, Industrial course. Tumba, Sweden, March 23–24.

Instrumentation and control for optimizatin and smartness, Invited lecture. Workshop arranged by ABB Industri AS, Oslo, Norway, April 22.

Introduction to automatic control, Invited lecture. Food Technology Education (YTH). Lund Institute of Technology, Lund, Sweden, May 18.

Model Control–How to use the potential, Invited lecture. Process Automation 1999 fair, Oslo, Norway, June 1.

Supervision and detection, Invited lecture. AssiDomän, Frövi, Sweden, June 16.

PID control, Industrial course. Lund Institute of Technology, Lund, Sweden, Nov 2 and 9.

Process Control in Practice, Industrial course. Stockholm, Sweden, Nov 16.

Automatic Control, Invited lecture. Celsius, Bofors, Sweden, Nov 17.

Process Control in Practice, Industrial course. Tumba, Sweden, Dec 7–8.

Johansson, Rolf

System identification of atrial activation during chronic atrial fibrillation in man, Invited paper at IFAC World Congress (IFAC'99), Beijing, P.R. China, July 6.

The Yakubovich-Kalman-Popov Lemma for Stability Analysis of Dynamic Output Feedback Systems, IFAC World Congress (IFAC'99), Beijing, P.R. China, July 8.

The Yakubovich-Kalman-Popov lemma and Stability Analysis of Dynamic Output Feedback Systems, Willett Seminar in Control, University of Illinois at Urbana-Champaign, August 5.

*The Yakubovich-Kalman-Popov lemma and Stability Analysis of Dynamic Output Feedback Systems,*University of California at Santa Barbara, August 13.

Interactive On-Line Evaluation of Robot Motion Control, 1999 IEEE Int. Conf. Control Applications and the Symp. Computer Aided Control Systems Design (CCA'99&CACSD'99), Kohala Coast, Hawaii, August 24.

Stop-and-Go Controller for Adaptive Cruise Control, 1999 IEEE Int. Conf. Control Applications and the Symp. Computer Aided Control Systems Design (CCA'99&CACSD'99), Kohala Coast, Hawaii, August 25.

Correlation Methods of Continuous-Time State-Space Model Identification, Invited paper, European Control Conf. (ECC'99), Karlsruhe, Germany, September 3.

Stability Analysis of Adaptive Output Feedback Control, IEEE Conf. Decision and Control (CDC'99), Phoenix, Arizona, December 8.

Johnsson, Charlotta

Grafchart and batch recipe structures, the conference Interphex '99, New York, April 20–22.

Möllerstedt, Erik

Stability Analysis of Electric Networks using Linear Time Periodic Models, Invited lecture, Dept of Math, Royal Inst. of Tech., Stockholm, Sweden

Panagopoulos, Hélène

Design of PID Controllers Based on Optimization, Invited lecture, AssiDomän, Frövi, Sweden, June 16.

PID Controller Design, Invited lecture, UCLA, Los Angeles, California, August 18.

Design of PID Controllers Based on Optimization, Invited lecture, Sigma Exallon Systems, Malmö, Sweden, November 16.

Rantzer, Anders

Optimization of Integral Quadratic Constraints, Invited lecture. Workshop on LMI Methods in and Control, Compiègne, France, May 18.

On the Robustness of Simulated Trajectories, Invited lecture. Int. Workshop on Control of Uncertain Systems, Hong Kong, July 1.

Convex Dynamic Programming, 14th IFAC World Congress, Beijing, P.R. China, July 7.

Stability of Piecewise Linear Systems, Invited lecture. Workshop on Dynamics of Switching, Liege, August 30

A Simple Performance Criterion for Anti-Windup Compensators, Invited lecture. European Control Conference, Karlsruhe, September 3.

Automatic Control—A historical overview with industrial applications, Invited lecture. Dansk Automationsselskab, Copenhagen, October 7.

Analysis tools from the theory of robust control, Invited lecture. Workshop on Stability of initial value ODEs, DAEs and their discretizations, Frostavallen, Höör, Sweden, October 15.

Tummescheit, Hubertus

Physical System Modeling with Modelica, Seminar. IFAC World Congress, Beijing, P.R. China. July 9.

Object-Oriented Modeling of Physical Systems with Modelica, Invited seminar. Deparment of Automatic Control, Hamburg, Germany, November 16.

Wallén, Anders

A Tool For Rapid System Identification, IEEE International Conference on Control Applications, Kohala Coast, Hawaii, August 25.

Wittenmark, Björn

PhD course in process control, Lectures within the research program Center for Chemical Process Design and Control, Chalmers, October 20–21.

15. Seminars at the Department

Seminars presented in order of date. The seminars were given at the department during 1998, both by the staff and by invited lecturers. Dissertations and master theses presentations are also included.

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

Jan 19: **Naomi E. Leonard** (Princeton University), *Controlled Lagrangians and the Stabilization of Mechanical Systems.*

Jan 20: **Eduardo Quiles** (Technical University of Valencia), *Reliability modeling and simulation of power distribution systems.*

Jan 21: **Anders Nilsson-Stig, Henrik Perbeck** (LTH), *Equalization of Co-Channel Interference in Future Mobile Communication Systems.* MSc-thesis presentation.

Jan 21: **Naomi E. Leonard** (Princeton University), *Mechanics and Nonlinear Control: Making Underwater Vehicles Ride and Glide.*

Feb 10: **Karl-Erik Årzén et al.** (AC), *Lund–Nantes Project Course in Discrete Systems.*

Feb 10: **Ricardo Sanz** (Universidad Politecnica de Madrid), *Distributed Objects for Control Systems.*

Feb 11: **Ricardo Sanz**, *Patterns for Intelligent Controllers.*

Feb 16: **Bo Lincoln** (AC), *Active Structural Acoustic Control of Noise From Personal Computers.*

Feb 19: **Anders Hedin** (LTH), *A New Control Concept for Haldex limited slip coupling.* MSc-thesis presentation.

March 9: **Ioannis Kanellakopoulos** (UCLA), *Backstepping: Theory and Applications.*

March 11: **Ioannis Kanellakopoulos** (UCLA), *Active Identification for Discrete-Time Nonlinear Systems.*

March 12: **Ioannis Kanellakopoulos**, *Autonomous Vehicle Systems in Control Research and Education.*

March 18: **Mikael Cordes, Andreas Johansson** (LTH), *Synchronization in ADSL Modems.* MSc-thesis presentation.

March 22, 23, 25: **Stephen Boyd** (Stanford University), *Convex Optimization with Engineering Applications.* Five seminars. Short course for graduate students.

March 24: **Rodolphe Sepulchre** (Université de Liège), *Achieving Large Regions of Attractions in Control Design.*

March 25: **Charlotta Johnsson** (AC), *A Graphical Language for Batch Control.* Doctoral dissertation defence.

March 26: **Mikael Johansson** (AC), *Piecewise Linear Control Systems.* Doctoral dissertation defence.

March 26: **Lennart Ljung** (Linköping University), *Bayesian Terrain-Aided Navigation.*

March 29: **Magnus Bengtsson, Ola Örsmark** (LTH), *Modeling and Control of an Hydraulic Actuator.* MSc-thesis presentation.

April 6: **Johan Bengtsson, Anders Ahlstrand** (LTH), *Robot Playing Scrabble using Vision Feedback.* MSc-thesis presentation.

April 7: **Joaquin Collado** (Université de Technologie de Compiegne), *Semi-Global Stabilization of Linear Systems with Bounded Inputs.*

April 7: **Rogelio Lozano** (Université de Technologie de Compiegne), *Control of Underactuated Mechanical Systems.*

April 15: **Joakim Kvistholm** (LTH), *Neural Networks in Extremal Seeking Control.* MSc-thesis presentation.

April 19: **Magnus Egerstedt** (KTH, Stockholm), *Control of Mobile Robot Platforms within a Behavior Based Framework.*

April 19: **Stefan Solyom** (Hungary), *Fuzzy State Controller for Linear and Nonlinear Systems.*

April 22: **Bengt Jönsson, Torkel Lundgren** (LTH), *Pressure Control of the Haldex Limited Slip Coupling.* MSc-thesis presentation.

April 27: **Martin Almers** (LTH), *Control of a Microscope.* MSc-thesis presentation.

April 27: **Wolfgang Reinelt** (Linköping University), *Robust Control of Systems with Hard Constraints.*

April 29: **Fredrik Rosdahl** (LTH), *Rejection of Multiple Sinusoids in Measurement Signals.* MSc-thesis presentation.

May 6: **Enrique Pico Marco** (U.P. Valencia), *Robust Control of a Flexible Servo with Parametric Uncertainty.* MSc-thesis presentation.

May 19: ***"Mechatronics Day."*** A seminar arranged by the department, presenting the following 7 seminars:

1. **David Auslander** (UC Berkeley), *Mechatronics and Control.*
2. **Hilding Elmqvist** (Dynasim AB), *Modelica and Mechatronics.*
3. **Gunnar Bolmsjö et al.** (Mech. Eng. LTH), *The Snake Robot.*
4. **Rolf Johansson et al.** (AC), *Open Robotic Systems.*
5. **Mats Alaküla** (IEA, LTH), *Electrical Motor Design.*
6. **Mattias Grundelius** (AC), *Motion Control of Fluid Containers.*
7. **Karl-Erik Årzén** (AC), *Teaching Realtime Systems.*

May 20: **Jimmie Landerman, Andrej Petef** (LTH), *Digital Speaker Equalization.* MSc-thesis presentation.

May 20: **Tamer Basar** (University of Urbana-Champaign), *Risk-Sensitive Controller Design for Nonlinear Systems and Relationship with Nonlinear H_∞ Control.*

May 21: **David Auslander** (UC Berkeley), *How Would You Approach Physics in 1720 If You Had a PC?.*

May 21: **Tamer Basar** (University of Urbana-Champaign), *Decentralized Control Methods for Flow Control in High-Speed Networks.*

May 25: **Lars Malcolm Pedersen** (AC), *Modeling and Control of Plate Mill Processes.* Doctoral dissertation defence.

June 6: **Albert Norberg** (LHT), *Extended Relay Auto-tuning for PID Controllers Based on the Process Parameter kappa.* MSc-thesis presentation.

June 15: **Dan Block** (University of Illinois, Urbana-Champaign), *Overview of the College of Engineering Controls Lab.*

June 22: **Qing-Guo Wang** (National University of Singapore), *Dominant Pole Placement for Multi-Loop Control Systems.*

June 23: **Martin Lembke** (LTH), *Identification of Respiratory Mechanics during Mechanical Ventilation.* MSc-thesis presentation.

June 24: **Danny C. Sorensen** (Rice University), *Krylov Projection Methods for Model Reduction.*

June 28: **Qing-Guo Wang** (National University of Singapore), *Robust PID Controller Design via LMI Approach.*

June 29: **John Lygeros** (UC Berkeley), *Control of Hybrid and Large Scale Systems, Part I: Modeling.*

June 30: **John Lygeros** (UC Berkeley), *Control of Hybrid and Large Scale Systems, Part II: Controller Synthesis.*

July 7: **Niclas Lundqvist** (LTH), *Modelling of a Plate Exchanger System with Control on both the Steam and Secondary Side.* MSc-thesis presentation.

Aug 18: **Adam Steineck** (LTH), *Non-Linear Control of a Bouncing Ball.* MSc-thesis presentation.

Aug 23: **M. Vidyasagar** (Bangalore, India), *Randomized Algorithms for Robust Control.*

Aug 26: **Jorge Goncalves** (MIT), *Global Quadratic Stability of Limit Cycles is Common in Relay Feedback Systems.*

Aug 26: **P. R. Kumar** (University of Illinois), *The Traffic Carrying Capacity of Wireless Networks.*

Sep 2: **John Doyle** (CalTech), *Robustness and Complexity.*

Sep 2: **John Doyle** (CalTech), *Complexity and Robustness.*

Sep 6: **Steve Yurkovich** (Ohio State University), *Recent Results on Nonlinear Control for Internal Combustion Engines.*

Sep 8: **John Hauser** (CalTech), *Trajectory Exploration for Nonlinear Systems.*

Sep 13: **Rasmus Olsson** (AC), *On-Line Batch Process Monitoring using Multivariate Statistical Methods.*

Sep 17: **Jan H. van Schuppen** (CWI, Amsterdam), *Dynamic Route Control of Motorway Networks.*

Sep 17: **Sven Hedlund** (AC), *Computational Methods for Hybrid Systems.* Lic Tech dissertation seminar.

Sep 22: **Mattias Henriksson** (LTH), *Modeling of Glucose and Acetate Metabolism in Escherichia coli.* MSc-thesis presentation.

Sep 22: **Karl Johan Åström** (AC), *Automatic Control—The Hidden Technology.*

Sep 23: **John Hauser** (CalTech), *Modeling and Control of Flight Dynamics.*

Sep 24: **Lennart Andersson** (AC), *On Simplification of Models with Uncertainty.* Doctoral dissertation defence.

Sep 28: **John Hauser** (CalTech), *Unconstrained Receding Horizon Control of Nonlinear Systems.*

Sep 29: **Simon Ungerbrandt** (LTH), *Product Test Bench Based on Real-Time Simulation.* MSc-thesis presentation.

Sep 29: **Stéphane Velut** (ENSIEG (INPG), Grenoble), *Control of Substrate Feeding in E. coli Cultures.* MSc-thesis presentation.

Sep 29: **Henrik Sandberg** (LTH), *Nonlinear Modeling of Locomotive Propulsion System and Control.* MSc-thesis presentation.

Sep 30: **Magnus Svensson** (Chalmers), *Reglering av trottel-servo med hjälp av QFT (Control of Throttle Servo Using QFT).*

Oct 28: **Pär Olsson** (LTH), *Automatic Sypervision and Diagnosis of a Paper Machine.* MSc-thesis presentation.

Nov 2: **John Baras** (University of Maryland), *Classification and Control from Compressed Data.*

Nov 3: **Martin Nilsson** (LTH), H_∞ *Centering Controller for Single-Wheel Drive Equipped Bogie.* MSc-thesis presentation.

Nov 10: **Mark Spong** (University of Illinois), *YAPP: Yet Another Pendulum Project.*

Nov 11: **Klaus Schilling** (FH Ravensburg-Weingarten), *From Mars to Education : Teleoperations of Robots at the University of Applied Sciences FH Ravensburg-Weingarten.*

Nov 12: **Mark Spong** (University of Illinois), *Impact Mechanics and Robot Air Hockey.*

Nov 19: **Daniel Sandberg** (LTH), *System Identification for Modelling of Stock Index.* MSc-thesis presentation.

Nov 23: **Michel Gevers** (Université Catholique de Louvain, Belgium), *Identification and Validation for Robust Control: Design Issues.*

Nov 24–26: ***"Minicourse on MPC,"*** eight seminars by **Jan Maciejowski** (Cambridge university):

1. Introduction: Motivation, Basic ideas.
2. Basic Formulation and Solution of MPC.
3. Hands-on Experience of the Toolbox.
4. Other Formulations.
5. Tuning and Stability.
6. Hands-on Experience of the Toolbox.
7. Robust MPC; Nonlinear MPC; Perspectives.
8. Discussion and Introduction to the Project.

Nov 30: **Lars Gustafsson, Mikael Olsson** (LTH), *Robust On-line Estimation.*MSc-thesis presentation.

Dec 1: **Ken Tindell** (Jönköping), *Fixed-Priority Scheduling.*

Dec 2: **Johan Eker** (AC), *Flexible Embedded Control Systems—Design and Implementation.* Doctoral dissertation defence.

Dec 9: **Olaf Bauer** (LTH), *Modelling of Two-phase Flows in Modelica.* MSc-thesis presentation.

Dec 14: **Walter Schaufelberger** (ETH Switzerland), *Use of the WWW in Control Engineering Education.*

Dec 16: **Anders Robertsson** (AC), *On Observer-Based Control of Nonlinear Systems.* Doctoral dissertation defence.

Dec 16: **Thor I. Fossen** (Norwegian University of Science and Technology), *Nonlinear and Adaptive Weather Optimal Positioning Control (WOPC) of Ships: Experimental Results with CyberShip 1.*

Dec 17: **Mats Åkesson** (AC), *Probing Control of Glucose Feeding in Escherichia coli Cultivations.* Doctoral dissertation defence.

Dec 17: **Bruno Siciliano** (University of Naples), *Six-DOF Impedance Control of Robot Manipulators.*

Dec 20: **Henrik Lannegren** (LTH), *Motion Control with Slosh Suppression.* MSc-thesis presentation.