

# Activity Report: Automatic Control 2003

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Activity Report

# Automatic Control

# 2003


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# Contents

# 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, 2003.

The budget for 2003 was 26 MSEK. The proportion coming from the University was 52%.

Five PhD theses were defended this year, by Ari Ingimundarson, Anton Cervin, Magnus Gäfvert, Bo Lincoln, and Sven Hedlund. This brings the total number of PhDs graduating from our department to 68. Four Licentiate theses were completed, by Ola Slätteke, Jacob Svendenius, Dan Henriksson, and Johan Åkesson. Eight new PhD students have been admitted during the year: Andreas Wernrud, Peter Alriksson, Oskar Nilsson, Brad Schofield, Ather Gattami, Pontus Nordfeldt, Martin A. Kjaer, and Martin Andersson. Two persons with doctor's degree left the department: Ari Ingimundarson started to work for Automatic Control & Computer Engineering Department in Terrassa, Spain, and Sven Hedlund started to work for Tetra Pak AB in Lund. Ove Glenberg also left our department during the year. Bo Bernhardsson, one of our professors, is on temporary leave working for Ericsson Mobile Platforms AB, Lund.

In the civilingenjör (master) program we have 11 courses. The total number of students who finished the courses were 913, and 21 students completed their master theses. The total teaching effort corresponds to 125 full-year equivalents.

Research at the department is presented under the following headlines: Nonlinear and Uncertain Systems, Modeling and Simulation, Process Control, Biotechnology Processes, Robotics, Real-Time Control, Biomedical Systems, and Automotive Systems.

Today the department has seven professors and one professor emeritus.

In May 2003 Prof. Graham C. Goodwin became an honarary doctor of Lund University. Goodwin is one of the leading researchers of the world in automatic control. Since 1974 has has been at the University of Necastle, New South Wales, Australia. He has authored and co-authored seven books and hundreds of research papers.

Goodwin has above all been working in the fields of system identification, adaptive control, and process control. His work on stability and convergence of adaptive systems is very well-known in our field.

Graham Goodwin has obtained several international awards for his work as researcher and scholar, for instance, IEEE Control Systems Society, 1999 Henrik Bode Lecture Prize, and Best Engineering Text Book Award from the International Federation of Automatic Control. He is a Fellow of IEEE, Honarary Fellow of Institute of Engineers, Australia, Fellow of the Australian Academy of Technology, Science, and Engineering, and Fellow of the Royal Society, London. Further, he is one of the few reciepients of the Australian Research Council Federation Fellowship.

At the University of Newcastle Goodwin has created a research group that is very strong in both theory and applications. Graham Goodwin has helped to develop a large exchange of students and researchers between Newcastle and Lund and is one of the members of the Scientific Advisory Board of our department.

Some statistics from five years is given in the table below.

| | 99 | 00 | 01 | 02 | 03 | Sum |
|---|---|---|---|---|---|---|
| Books | 2 | 0 | 0 | 1 | 4 | 7 |
| Papers | 24 | 18 | 16 | 21 | 13 | 92 |
| Conference papers | 45 | 37 | 20 | 44 | 31 | 177 |
| PhD theses | 7 | 3 | 2 | 1 | 5 | 18 |
| Licentiate theses | 1 | 1 | 1 | 3 | 4 | 10 |
| Master theses | 25 | 24 | 23 | 18 | 19 | 109 |
| Internal reports | 8 | 5 | 5 | 7 | 2 | 27 |

**Acknowledgments**

We want to thank our sponsors, ABB Robotics, EU Commission, Honda, Institute Mittag-Leffler, Kranendonk Production Systems BV, The Royal Swedish Academy of Sciences, The Swedish Agency for Innovation Systems (VINNOVA), Swedish Research Council, Swedish Energy Agency (CECOST), Swedish Foundation for Strategic Research (SSF), Toyota Motor Corporation.

# 2. Internet Services

## World Wide Web

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

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

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

## Electronic Mail

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

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

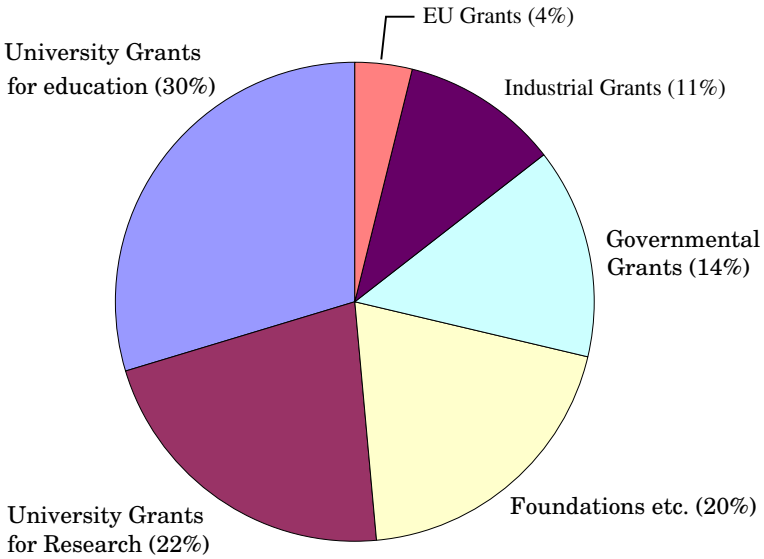
Our web page `http://www.control.lth.se/people/telemail.html` contains a complete list of email addresses and phone numbers. The department also has a generic email address:

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

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

# 3. Economy and Facilities

The turnover for 2003 was 26 MSEK. The income comes from Lund University (52%) 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 2003 we had the following contracts:

- VR – Control of Complex and Nonlinear Systems (block grant)

- VR – Industrial Aspects of on-line Monitoring and Diagnosis
- VR – Theory for Modeling, Control and Analysis of Periodic Systems
- VR – Control and Verification of Systems with State Constraints
- VINNOVA – Process Control for Cultivation of Micro Organisms
- VINNOVA – Lund Center for Applied Software Research (LUCAS)
- VINNOVA – Green Car HCCI
- 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 and Scheduling
- EU/GROWTH – Advanced Decision Systems for the Chemical/Petrochemical Manufacturing Industries (CHEM)
- EU HPRN-CT - Nonlinear and adaptive control (NACO2)
- EU IST 2001-33520 – Control and Computation (CC)
- EU IST 2001-37652 – Hard Real-time CORBA (HRTC)
- ABB Automation Technology Products/Business Unit Robotics (Research Collaboration)
- ABB – PhD Research Project
- Alfa Laval Lund AB – Research and Development Agreement
- Mid Sweden University – PhD Research Project
- Haldex Brake Products AB – PhD Research Project
- NFO Control AB – PhD Research Project
- Toyota Motor Corporation – Simulation Model
- Swedish Energy Agency (CECOST)
- Johnson Controls Inc – Scholarship
- Royal Physiographic Society – Scholarship
- Jacob Letterstedt - Scholarship
- Knut and Alice Wallenberg – Scholarship
- Foundation Sigfrid and Walborg Nordkvist – Scholarship
- Foundation Aeryleanska Traveling Scholarship – Scholarship

The block grant from VR and the CPDC grant from SSF are long range and also some of the VINNOVA projects are 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 facilities are laboratories and computer systems. Almost all staff use PCs running Linux. Some, especially administrative staff, have a need for Microsoft Windows. In those cases the VMware product enables them to run both Linux and Windows at the same time.

The senior academic staff have laptop computers running either Linux plus VMware/Windows or pure Windows.

There is also a reasonably powerful central computer, which is used for certain types of 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 more than 1000 students, and on the average they spend about 20 hours each in the lab.

A certain amount of computer replacement has been done during the year, such that the teaching lab contains 40 PCs, the oldest ones delivered in 2000.

### New lab equipment and processes

***3D inertia wheel pendulum*** The spherical pendulum with inertial wheels, see Figure 3.1 was built by Rolf Braun after an idea by Anton Shiriaev, Univ of Southern Denmark, Odense. The pendulum moves on

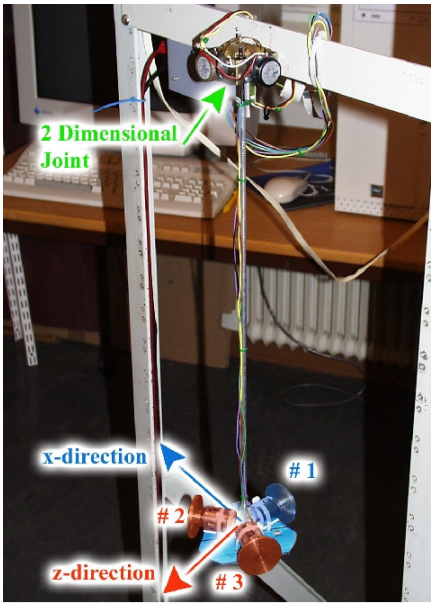



**Figure 3.1** Spherical pendulum with three servo driven inertia wheel actuators.

the surface of a sphere, but can not rotate around its axis. The actuators are three inertia wheels each controlled by a DC-motor and the position is measured with the XY-potentiometer at the pivot.

***A Detached Process Interface*** A detached process interface, having 4 analog inputs, 2 analog outputs, 6 digital inputs, and 6 digital outputs has been designed. It is connected to a computer through the serial port, and the sampling rate is about 100 samples/second. With this interface it will be possible to make control experiments in the field using an ordinary laptop as the process computer. It has been used successfully for control of an evaporative gas turbine at the Department of Thermal Power Engineering.

***Mini-Segway*** In a very ambitious student project four students, E. Montnémery, P. Clarberg, H. Kjellander, and C. Winfeldt, built the

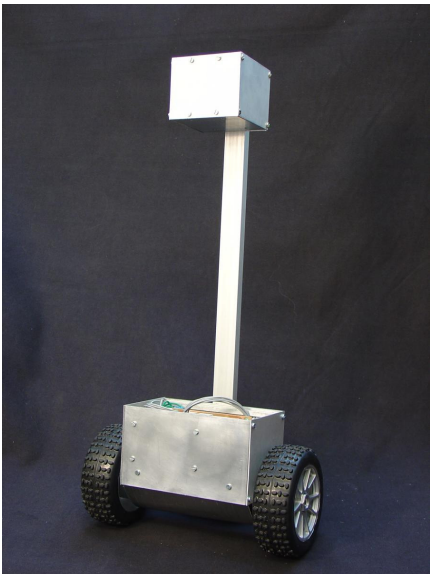


**Figure 3.2** Mini-segway built in a student project during the fall 2003.

mini-segway in Figure 3.2. The eight-week-project included all the mechanical and electronics design and a successful implementation of control algorithms for stabilization of the segway. An on-board AVR-processor was used with an R/C-interface for external reference values and high level path planning.

### Robotics Laboratory

The Robotics Laboratory, containing three industrial robot manipulators (Irb6, Irb2000, and Irb2400) together with the Open Robot Control architecture developed at the Dept of Automatic Control (see "Looking back on Robotics Research, Annual report 2000"), serves as a common experimental platform for research activities from many different departments and research groups (including the Departments of Automatic Control, Mech. Eng., Computer Science, Mathematical Sciences). System integration aspects of real-time research, task-level programming and high bandwidth feedback control play an important role.

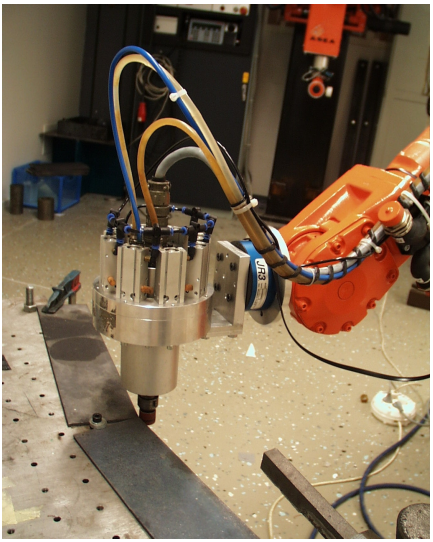


**Figure 3.3** Force controlled robot milling (stiff tool and stiff environment).

Matlab/Simulink interfaces for downloading and dynamically linking new control algorithms to the robot systems and the integration of external sensors such as e.g. force/torque sensors and stereo vision cameras, offer a powerful platform for research projects. It also allows for running student projects and master thesis projects using the facilities in the RobotLab in an easy manner.

A new generation of the Open Robot Control System based on the industrial ABB-controller S4C+ is developed in close corporation with ABB Robotics.

# 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 corresponds 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), Industrial Management and Engineering (I), Chemical Engineering (K), Environmental Engineering (W), and Information & Communication Engineering (C). Our courses are listed in Table 4.1. During 2003, 913 students passed our courses and 21 students completed their master's thesis projects. The number of registered students corresponded to 125 full-year equivalents during the year. The numbers for 2002 were 787, 21, and 130 respectively.

## 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 home-page, where the students can find course plans, lecture notes, documentation, manuals, old exams, etc.

We have also information sheets about the engineering courses and the doctorate program. You find the education links at `http://www.control.lth.se/education/`.

**Table 4.1** Courses and the number of students who passed.

| | |
|---|---|
| Reglerteknik AK–FEDIM *FRT010*<br>(Automatic Control, basic course) | 549 |
| Reglerteknik AK–C *FRT065*<br>(Automatic Control, basic course) | 17 |
| Processreglering (K) *FRT080*<br>(Automatic Process Control) | 12 |
| Systemteknik (W) *FRT110*<br>(Systems Engineering) | 49 |
| Digital Reglering *FRT020*<br>(Computer-Controlled Systems) | 77 |
| Realtidssystem *FRT031*<br>(Real-Time Systems) | 83 |
| Systemidentifiering *FRT041*<br>(System Identification) | 18 |
| Adaptiv reglering *FRT050*<br>(Adaptive Control) | 54 |
| Olinjär reglering och Servosystem *FRT075*<br>(Nonlinear Control and Servo Systems) | 36 |
| Internationell projektkurs i reglerteknik *FRT100*<br>(International Project Course in Automatic Control) | 5 |
| Projekt i reglerteknik *FRT090*<br>(Project in Automatic Control) | 13 |
| Examensarbete 20 poäng *FRT820*<br>(Master-thesis project, 5 months) | 21 |

## Doctorate Program

Five PhD theses were defended by Ari Ingimundarson, Anton Cervin, Magnus Gäfvert, Bo Lincoln, and Sven Hedlund. This brings the total number of PhDs graduating from our department to 68. Four licentiate theses were completed by Ola Slätteke, Jacob Svendenius, Dan Henriksson, and Johan Åkesson. Abstracts of the theses are given in Chapter 7.

We have admitted eight new PhD students during the year: Peter Alriksson, Andreas Wernrud, Martin Andersson, Ather Gattami, Martin A. Kjaer, Oskar Nilsson, Pontus Nordfeldt, and Brad Schofield.

The following PhD courses were given:

- Nonlinear Control Theory (A. Robertsson) 5 points
- Robotics (R. Johansson, A. Robertsson) 5 points
- Robust Control (A. Rantzer) 5 points
- Real-Time Systems (K-E. Årzén) 5 points
- Adaptive System Theory, (R. Johansson) 3 points
- Convex Optimization with Applications (A. Rantzer) 5 points
- Embedded Systems (B. Lincoln and A. Blomdell) 2 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
- Biotechnology Processes
- Robotics
- Real-Time Control
- Biomedical Systems
- Automotive Systems

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

## Nonlinear and Uncertain Systems

### Control of Nonlinear and Uncertain Systems

*Researchers: Sven Hedlund, Anders Rantzer, Chung-Yao Kao, Bo Lincoln and Stephen Prajna*

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 applications. Our main investigations deal with stability and robustness analysis as well as controller optimization.

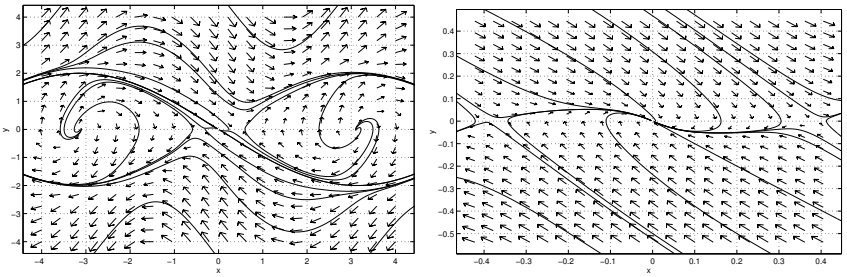


**Figure 5.1** Left: Phase plot for smooth pendulum swing-up control. Right: Magnified phase plot near upright equilibrium.

Recently, we reached a considerable breakthrough in the analysis of nonlinear systems. Most classical analysis methods have been based on Lyapunov functions. This is a very strong theoretical tool, but has important shortcomings in the context of control synthesis. In particular, the set of control Lyapunov functions for a given system is generally non-convex and even disconnected. Our new result gives an alternative approach to stability of nonlinear systems, which can be viewed as a dual to Lyapunov's theory. It is different in the sense that all implications are stated in terms of "almost all trajectories" of the system. Furthermore, the new criterion enjoys a powerful convexity property in control synthesis.

As an application of the new criterion, we have derived the first known globally smooth feedback law for swing-up and stabilization of an inverted pendulum. A two-dimensional phase plot of the closed loop system is shown in Figure 5.1

For several years, we have been developing the analysis framework based on integral quadratic constraints in cooperation with Prof. A. Megretski at MIT. Currently, our work is focused on constraints for time-varying time-delays. This makes it possible to treat performance degradation due to delays in the communication network used for control.

## Hybrid Control

*Researchers: Peter Alriksson, Sven Hedlund, Bo Lincoln, Stefan Solyom, and Anders Rantzer*

Hybrid systems is an active research area on the border between Computer Science and Automatic Control. A typical hybrid system consists of a physical process under control and supervision of a discrete computer. Not only computers, but also some physical phenomena are conveniently modeled as discrete events. Examples are mechanical systems with backlash, dead zones, and static friction, or electrical systems with switches. The department is involved in several projects devoted to hybrid control and computational approaches are developed for both analysis and synthesis.

A very promising synthesis approach is currently developed within the project based on classical dynamic programming. This method was introduced by Bellman in the 1950s and has found many important applications since then. The idea is general and very simple, but the "curse of dimensionality" is often prohibitive and restricts most applications to a discrete state space of moderate size.

We have recently initiated a very exciting development based on approximations of the cost function. It turns out that the exponential complexity of traditional dynamic programming algorithms often can be drastically reduced by relaxing the demand for optimality. An example of a problem where this method has been applied is the design of a switched power controller for DC to DC conversion. The idea is to use a set of semiconductor switches to effectively change polarity of a voltage source, and the controller has to decide which polarity to use each time slot so that the load voltage and current are kept as constant as possible; see Figure 5.2. In this case, the synthesis problem itself is very hard, and therefore we are happy if our algorithm can find a controller which yields less than twice the optimal cost. Using our Relaxed Dynamic Programming method with this slack gives us the explicit control law depicted in Figure 5.3. This law has been simulated for varying load current in Figure 5.4, and as can be seen, it successfully stabilizes the voltage around the nominal value of 0.5.

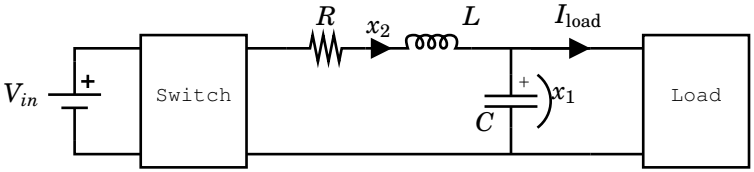



**Figure 5.2** The setup for the switched DC/DC-converter.

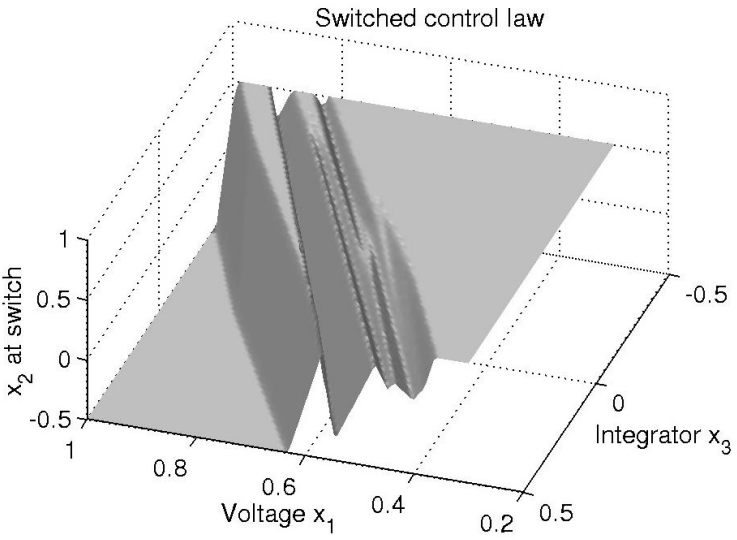



**Figure 5.3** The resulting switching feedback law is monotonous in the current, $x_2$ (by observation), and therefore it can be plotted in 3D. The plot shows at which current $x_2$ the switch from $s(n) = +1$ to $s(n) = -1$ takes place for varying voltages $x_1$ and integral states $x_3$. Note that the gridding is only for plotting purposes.

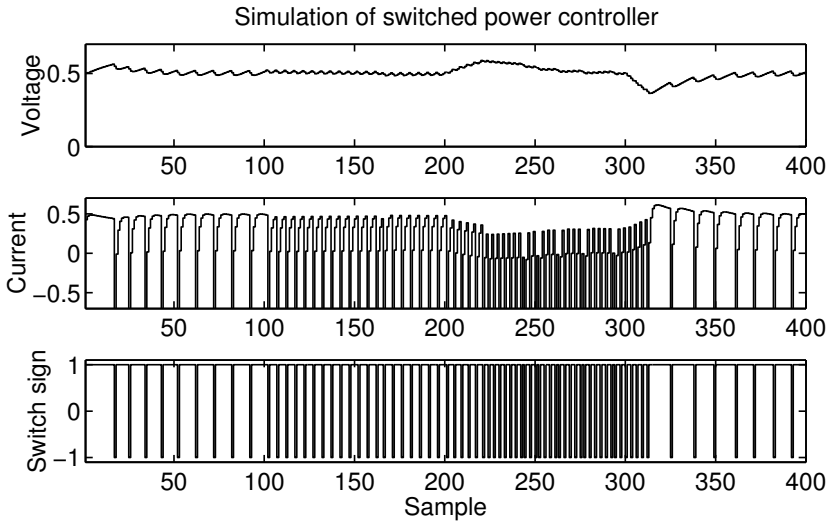



**Figure 5.4** A simulation of the power system example with the obtained controller. At $n = 100$, the load current $I_{\text{load}}$ is changed from its nominal 0.3A to 0.1A, at $n = 200$, to $-0.2$A and at $n = 300$ back to the nominal 0.3A. The reference value for the voltage is 0.5V

**Theory for modeling, control, and analysis of periodic systems**
*Researchers: Henrik Sandberg, Anders Rantzer, Bo Bernhardsson, and Magnus Fontes (Department of Mathematics, LTH)*

The goal of this project is to study periodic systems and how they may be represented and used for control and analysis. Periodic systems are common both in the natural sciences and in engineering. In the 19th century, for example, periodic models were used to study the motion of the moon and to model steam engines. Today they are used to model for example sampled-data systems, helicopter rotors, wind mills, and AC power systems.

The focus of the research at the department is on frequency-domain representations of periodic systems and on their properties. Frequency-domain analysis is often used for analysis of time-invariant models, and it is natural to look for extensions to periodic systems. A former PhD at the department, Erik Möllerstedt, used a frequency response operator, called the harmonic transfer function, to model AC power systems. This proved to be successful for detecting and analyzing instabilities that were caused by interaction of multiple harmonics on power lines.

Even though the harmonic transfer function formally fulfills many well-known relations for normal transfer functions, the precise meaning and correctness of the formulas are often unknown in the periodic case. The difficulties stem from the fact that the harmonic transfer function is an infinite-dimensional operator. To make computations in practice, it is then important to study the convergence of finite-dimensional approximations.

During 2003 we have studied the interaction between time-varying Markov parameters and the rate of convergence of certain types of approximations. Furthermore, we have identified a set of periodic impulse responses that can be used to compute the harmonic transfer function directly. In previous work, one had to first solve a realization problem. In this new framework we can treat, for example, systems with time-varying time delays which do not have a finite realization.

## Modeling and Simulation

### Reduction and Aggregation of Process Models

*Researchers: Henrik Sandberg and Anders Rantzer*

The goal of this project is to find methods and tools to simplify complex nonlinear or time-varying process models and to aggregate the effects of many small components.

The background for this work is that large complex mathematical models are regularly used for simulation and prediction. However, in control design it is common practice to work with as simple models as possible, often linear and time-invariant, because they are easier to analyze and evaluate. Real experiments or simulations using more accurate models are used to verify that the suggested controller really works well.

This is one reason why there is a strong need for methods and tools that can take a complex model and deduce simple models for various purposes such as control design. A more general reason is that simplified models are useful to point out the basic properties of a system and can provide good insight. Our approach to model simplification has so far been based on linearization around trajectories. This results in time-varying linear models which can capture many effects not seen in linear time-invariant modeling, such as frequency coupling. We have used a method called balanced truncation to simplify the models. Until recently balanced truncation for time-varying systems has only been justified by *ad hoc* arguments. However, based on work done by our group and others, it is now possible to derive *a priori* error bounds that in many situations can guarantee good approximations and help in the model selection process.

During 2003 the work has been focused on numerical issues for balanced truncation of linear time-varying models. In Figure 5.5 some results from tests on a diesel exhaust catalyst model are shown.

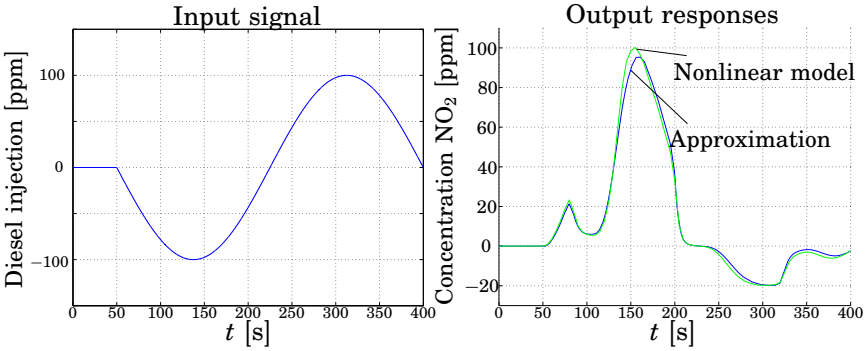



**Figure 5.5** By injecting some extra diesel into the combustion catalyst the $NO_x$-levels in the exhausts can be decreased. To the right the responses of a 24th-order nonlinear catalyst model and a first-order approximation to a sine wave diesel injection (left) can be seen. As seen, the number of equations can be significantly reduced without losing much accuracy.

For linear time-invariant systems an alternative method to balanced truncation is Hankel norm minimization. Mathematicians have developed similar tools also for time-varying systems, but it is not clear if all the nice properties of time-invariant Hankel norm approximations also hold in the time-varying case. Comparisons between balanced truncation and Hankel norm approximation is a topic for future studies.

## Process Control

### Advanced Decision Support Systems for the Chemical/Petrochemical Manufacturing Industries (CHEM)

*Researchers: Karl-Erik Årzén, Johan Åkesson, Rasmus Olsson*

The aim of the EU/GROWTH project CHEM ( `http://www.chem-dss.org`) is to develop an integrated set of toolboxes for various operator support functions in the process industries. CHEM started April 1, 2001 and will last for three years. The partners within CHEM are: Institut Francais de Petrol, France (Coordinator), Corus (ex. British

Steel), UK, Computas, Norway, Gensym, France, KCL, Finland, LAAS, Toulouse, France, LAG, Grenoble, France, Lund University, Metso Automation, Finland, Thales (ex Thomson), France, Universitat Politecnica de Catalunya, Spain, Université des Sciences et Technologies de Lille (LAIL), France, Universitat de Girona, Spain, UPM Kymmene, Finland, VTT Automation, Finland, Warsaw University of Technology, Poland, and ZAP, Poland.

The Department of Automatic Control is responsible for the development of an operating procedure handling toolbox that will be used to support the operators in process state transitions. The toolbox is named JGrafchart and consists of of graphical procedure language editor and its associated runtime system. The JGrafchart language combines ideas from Grafcet/Sequential Function Charts, Statecharts, and object-oriented programming. Within CHEM, JGrafchart will also be used for implementing a batch recipe execution systems and as an activity flow modeling language.

JGrafchart currently supports the following features:

- Steps and transitions with parallel and alternative branches
- Macro steps with exception transitions, multiple input and output ports, and the possibility to resume execution.
- Procedures and processes with support for parameter passing using call by value or call be reference
- Connection posts and step fusion sets.
- Hierarchically structured workspaces
- Lexically scoped name spaces
- Simple variables with four base types, and complex variables.
- Digital IO, analog IO, socket-based IO, and XML-based IO.
- XML-based storage on file.
- Support for select, connect, move, delete, undo, redo, copy, paste, cut, change size, zoom, pan, scroll, group, move to front, and print.

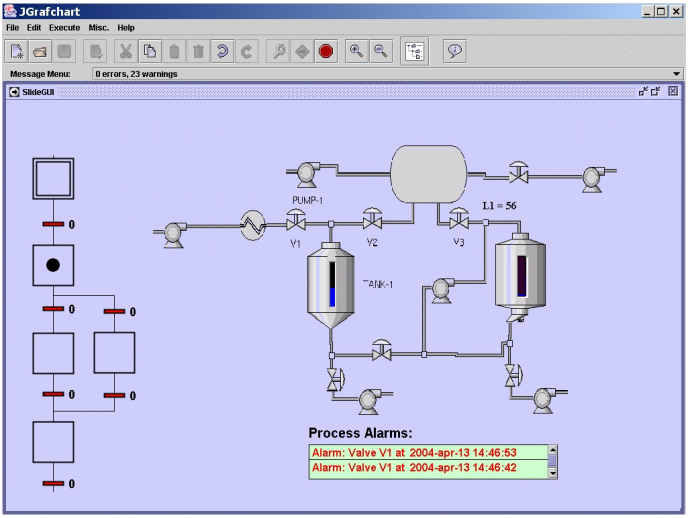



**Figure 5.6** Screenshot of JGrafchart

- Support for general graphical objects (rectangles, ellipses, texts, lines, icons, buttons, ...)

- Support for animated GUIs.

- On-line help and a built-in interactive tutorial.

JGrafchart is implemented in Java and Swing. A screenshot of JGrafchart is shown in Figure 5.6. JGrafchart is publically available at `http://www.control.lth.se/~karlerik/Grafchart/JGrafchart.html`.

Within CHEM the department is also investigating the possibility to use numerical optimization techniques for grade change sequence generation. Different optimization schemes have been investigated, including MPC. The aim is to include the grade change generation with JGrafchart through automatic generation of grade change sequences.

### Control and diagnosis in batch processes

*Researchers: Rasmus Olsson and Karl-Erik Årzén*

The aim of this project is to study integrated information and control systems for batch production. Special emphasis is put on integration of the monitoring and supervision tasks with recipe-based production. Two main issues is under investigation. The first issue studies the interaction between recipe execution and supervision. A model-based approach is taken where an internal unit model is used to check the validity of the unit operations in the recipes online. The internal unit model will also be used to structure the representation of the basic interlocking logic for safety monitoring. The second issue concentrates on the use of historical data in monitoring and supervision of batch process.

The work in the first part of the project is a continuation of the work on recipe-based batch processes by Charlotta Johnsson. The work is based on JGrafchart, a graphical sequential programming language and its applications to batch recipe management and resource allocation. The focus of this part of the project is to extend JGrafchart by adding different features that support exception handling in batch production.

A collaboration has been started with Prof. Puigjaner's group at UPC in Barcelona. Our results have been applied to the PROCEL batch laboratory process at UPC. Our approach is integrated with the reactive batch scheduling software developed at UPC. Part of this work is financed by the CHEM EU project.

### Center for Chemical Process Design and Control (CPDC)

*Researchers: Karl-Erik Årzén, Per Hagander, Tore Hägglund, Staffan Haugwitz, Ari Ingimundarson, Rasmus Olsson, Henrik Sandberg, Ola Slätteke, 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. Program director for the program is Bernt Nilsson, Chemical Engineering, LTH.

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 projects at the department supported by the CPDC program are:

- Modeling and control of the drying sections of a paper machine
- Loop and quality assessment
  - Dead-time compensation in process control
  - Interaction measures in process control
- Reduction and aggregation of process models
- Control and diagnosis in batch processes
- Advanced reactor technology – Control of open plate reactor

**PID Control**

*Researchers: Karl Johan Åström, Tore Hägglund, Ari Ingimundarson, and Stefan Solyom*

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.

In the PhD theses *PID Control – Design, Extension, Application* by Hélène Panagopoulos, efficient design methods for PID controllers were presented. These methods are based on constrained optimization and require that a process transfer function is available.

During the last year, these design methods have been used to develop simple tuning rules that are based on simple process models obtained step or frequency response experiments. A sequence of five papers have been written that treat PI and PID control based on step and frequency response methods, and a combination of step and frequency responses.

### Control and supervision at grade changes

*Researchers: Jenny Ekvall, Tore Hägglund*

This is a joint project between the Network for Process Intelligence (NPI) at the Mid Sweden University and Lund University. The goal of the project is to develop strategies to improve control at planned or unplanned changes in production in process control plants.

In a first phase, the drying section in a paper mill is studied. The goal is to improve control of steam pressure and moisture content at paper web breaks so that the recovery to normal operation is obtained in a shorter time. The project is performed in collaboration with the paper mill M-real, Husum.

A model of a drying cylinder, describing the relation between the steam pressure and the cylinder temperature has been developed and implemented in Matlab-Simulink. The model has been validated through experiments performed at the M-real Husum mill. In a second phase of the project, this model will be used to derive optimal control of the steam pressure during paper breaks.

### Decentralized structures for industrial control

*Researchers: Pontus Nordfeldt, Tore Hägglund*

There is an unfortunate gap between the centralized computational approaches of multi-variable control theory and the common practice to design local control loops disregarding couplings and interaction. Today it appears that both approaches have reached a point of refinement where the gap can be reduced from both sides.

This project aims to revise and improve the basic modules for decentralized control, and to develop new. By increasing the performance of the modules, the usefulness of present MIMO control functions such as MPC will increase. In this way, we will try to decrease the gap between MIMO control functions and the state of the art of process control. The ideas to be investigated in this project are relevant not only for process control but is also of interest for general classes of multi-variable systems.

In a first stage, we will develop a new module building on experiences from PID control: a $2 \times 2$ controller, i.e. a controller with two inputs and two outputs.

The project is funded by The Swedish Research Council (VR).

**Control of an Open Plate Reactor**
*Researchers: Per Hagander and Staffan Haugwitz*

The project, which started in September 2002, is run by Alfa Laval in collaboration with several other universities and institutes, such as Le Laboratoire de Génie Chimique de Toulouse. During the year there were several project meetings in Sweden and in France. The project is funded by Alfa Laval and CPDC.

A plate reactor is a modified plate heat exchanger, where one side is used as a reactor, with reacting chemicals and the other side is used for heating/cooling purposes. Depending on the reaction, there is a need for the water flow to cool or heat the reactor, i.e. if the reaction is exothermic or endothermic. By combining a reactor and a plate heat exchanger, the resulting plate reactor has a substantially higher heat transfer capability compared to a normal tank reactor process, just to mention one of the advantages.

When the reactions are exothermic and fast, the reactants are often dissolved into low concentration solutions to ensure that the temperature in the tank reactor does not rise above a dangerous level. By using a plate reactor, solutions of higher concentrations can be used, thus increasing the productivity and safety.

The plate reactor can be approximated as a one dimensional tube reactor. A typical reaction can be stated as:

$$A + B \rightarrow C$$

Reactant A enters the tube reactor. Reactant B is injected in multiple places along the tube reactor, in order to use the entire length of the reactor. When reactant A and B mix, the substance C is produced. If the reaction is exothermic, heat is generated and the temperature of the fluid increases. For each injection point, there will be a local temperature maximum. To cool the reactor cold water flows on each side of the reactor.

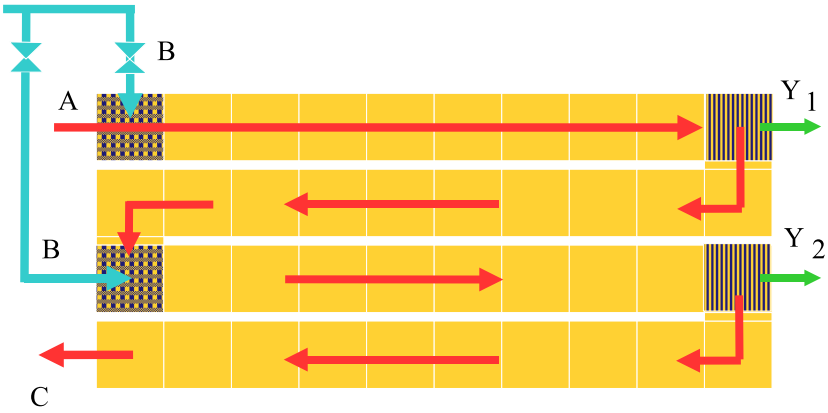



**Figure 5.7** A schematic figure of the reactor part of a plate reactor. The primary reactant A enters from the top left. The secondary reactant B is injected at multiple points along the length of the reactor. $Y_1$ and $Y_2$ are measurement signals to the control system, which can control the flow rates of the reactant injections or the distribution of flow rate between the injection points.

The reactor construction is very flexible, where the number of plates, injection sites and sensor locations can be varied to fit various chemical reactions. Internal sensors inside the reactor, which directly monitor the process, lead to better process knowledge and together with internal injections sites enable a new way of process control.

The primary control objective is to keep the process at a pre-calculated optimal operating point, regardless of perturbations. One crucial part of the control system will be the start-up procedure. The control system will also be involved in the safety management part, e.g. to prevent the reactor temperature to rise above a certain critical limit or to take appropriate actions during different types of reactor failures. The objectives of the control system can be summarized as:

- Utilize reactor maximally in a safe way
- Reaction is to be completed within the reactor
- Reactants are to be in the right proportions
- Should be able to work with highly concentrated solutions
- Avoid side reactions
- Achieve and maintain desired operating conditions
- Fast and safe start-up/shut-down
- Emergency shut-down procedure
- Robustness towards disturbances in the process

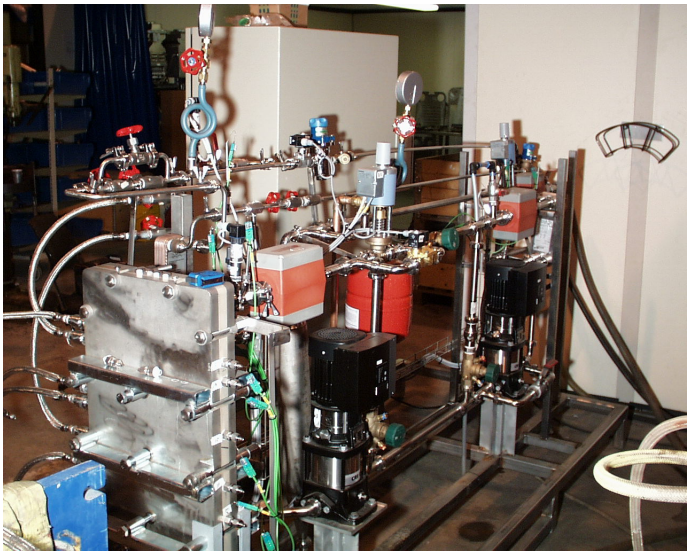


**Figure 5.8** The experimental test unit, with the plate reactor to the left.

In order to adequately cool the reactor, a utility system has been designed, which feeds the reactor with cold water with appropriate temperature and flow rate. A temperature controller to the utility system has been developed. The utility system, seen in Figure 5.8, has been assembled at Alfa Laval facilities in Lund. Experiments to investigate the control properties of the plate reactor and to test the utility control system have been conducted.

### Modeling and Control of the Drying Sections of a Paper Machine

*Researchers: Ola Slätteke, ABB and LTH, Björn Wittenmark, and Tore Hägglund, in cooperation with Krister Forsman, ReglerDoktorn AB*

The paper making process is essentially a very large drainage process. Consistency of the stock flow entering the paper machine head box is typically around 0.2% – 1.0% (2–10 g fiber per kg water). Although the drying section is responsible for removing less than 1% of this water

content, this is the part of the paper machine that, by far, consumes most energy. It is also in the drying section where most paper web strength forms and web shrinkage occurs and the part where the actual moisture control is performed. These are some of the reasons why this part of the paper machine is critical for the final paper qualities.

A dryer section in a paper machine can consist of up to one hundred steam heated cylinder and the length of the drying section can be above 100 meters, see Figure 5.9. The cylinders are divided in 5–10 steam groups. The control of the steam pressure in these cylinder groups is in cascade control with the moisture control loop. This project is focused on the modeling and control tuning of this process. From mathematical model building and experiments on industrial paper machines it is found that the dynamics from the steam valve to the steam pressure in the cylinders can be described by a simple process model, the so called IPZ model. This model has an integrator, an additional pole, and one zero. The dynamics from the steam pressure set point to the moisture in the paper can be described by a first order model plus dead time, where the dead time is a dominating part.

So far, a simple tuning method for the pressure controller (a PI-controller) has been developed that is based on the four process parameters of the IPZ model. These process parameters can easily be obtained by a simple open loop step response. The tuning rule has been demonstrated on a few different paper machines in Sweden. Also, a model for the steam pressure based on first principles has been developed and verified against real plant data.

### Control Loop Structure Assessment

*Researchers: Mikael Petersson, Tore Hägglund, and Karl-Erik Årzén*

The work is focused on assessing the control loop structure based on available measurements. The scenario studied consists of a SISO control loop that contains an additional exogenous signal. Methods have been developed that decides whether or not the additional signal affects the control performance, in which way it affects the control loop, if it is possible to compensate for the exogenous signal by using, for example,

**Figure 5.9** Schematic illustration of a paper machine. The direction of the paper production is from left to right. The dryer section, with its steam heated cylinders, is the pink area in the picture. Before that is the wire section and the press section

feedforward, see Figure 5.10 or cascade control. Future activities lies in gain-scheduling and estimation of how much performance that can be gained by the compensation.

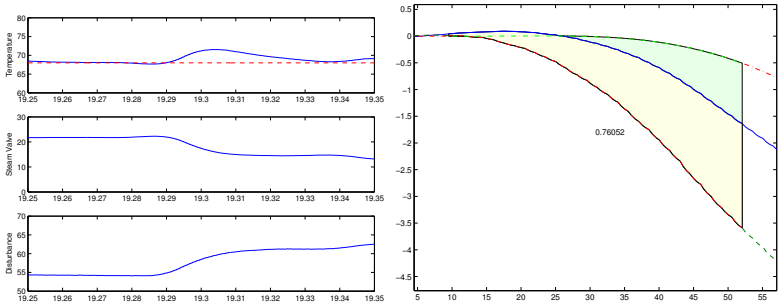



**Figure 5.10** A disturbance acting on a heat exchanger with temperature control. The disturbance has a Feedforward Index of 0.76, indicating that it is suitable for usage in feedforward control action.

During 2003, the research has focused on industrial experiments. This project is funded by VR/SSF in cooperation with ABB, and consists of an industrial PhD-student position for Mikael Petersson.

## Biotechnology Processes

### Control of Biotechnology Processes

*Researchers: Lena de Maré, Stéphane Velut, and Per Hagander in cooperation with Jan Peter Axelsson, Pharmacia AB, 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 are not easily 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 Pfizer, Strängnäs. 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 analyzed 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 Departments of Biotechnology and Chemical Engineering, Lund University, at Active Biotech, in Lund and at SBL Vaccin, Stockholm, at Pharmacia AB, Stockholm and Strängnäs, and tested with different *E. coli* strains and operating conditions. Good cultivation conditions and high production levels could be obtained from the first experiment. The strategy is also tested with

good results in production scale and for other organisms like bakers yeast and cholera bacteria.

When the stirrer speed saturates it means that the maximal oxygen transfer capacity is reached, and the activity of cells is normally reduced by decreasing the glucose supply. An alternative is to reduce the temperature.

We are currently investigating a combined strategy to control the dissolved oxygen by both stirrer speed and temperature using midranging.

## Robotics

### Robotics Research and Nonlinear Systems Research

*Researchers: Rolf Johansson, Klas Nilsson, Anders Robertsson, Tomas Olsson, and Torgny Brogårdh, ABB Robotics*

The laboratory for robotics and real-time systems is centered around industrial robot manipulators; an ABB Irb-6, an ABB Irb-2000, and an ABB Irb-2400 robot. Hardware interfaces have been developed to create an open system suitable for control experiments. The computer hardware is VME-based with both microprocessors and signal processors integrated into an embedded system for hard real-time control. The system is connected to a network with 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 using robot vision and force sensing.

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.

The project Autofett aims towards use of force control in manufacturing operations such as robotized fettling. New sensor interfaces with modification of hardware and real-time software architectures have been developed to accommodate the use of force control algorithms based on work-space sensing.

### Vision-based Feedback or Robot Control

*Researchers: Tomas Olsson, Dan Henriksson, Anders Robotsson, and Rolf Johansson*

During the last years increased computational power has made vision an interesting feedback sensor to use also in more demanding applications, such as, for instance, in object tracking and visual servoing.

However, in vision-based feedback control systems, the time to obtain sensor information is usually non-negligible, and these systems thereby possess fundamentally different timing behavior compared to standard real-time control applications. For most image-based tracking algorithms, it is possible to trade-off the computational time versus the accuracy of the produced position/orientation estimates.

Research has resulted in a method for optimizing the use of computational resources in a multi-camera based positioning system. A simplified equation for the covariance of the position estimation error is calculated, which depends on the set of cameras used and the number of edge detection points in each image. An efficient algorithm for selection of a suitable subset of the available cameras is presented, which attempts to minimize the estimation covariance given a desired, prespecified maximum input-output latency of the feedback control loop.

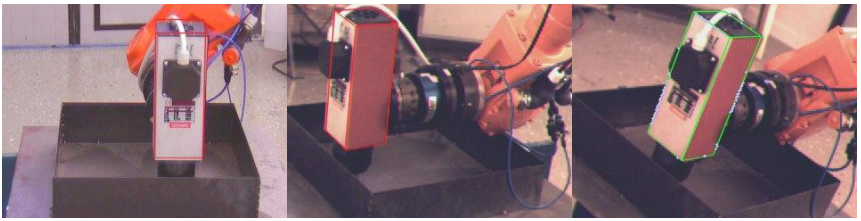


**Figure 5.11** Three different camera views for position tracking of object (tool) in a force/vision controlled robot experiment.

Simulations have been performed that capture the real-time properties of the vision-based tracking algorithm and the effects of the timing on the performance of the control system. The suggested strategy has been compared with heuristic algorithms, and it obtains large improvements in estimation accuracy and performance for objects both in free motion and under closed loop position control.

A flexible method for six degree-of-freedom combined vision/force control for interaction with a stiff uncalibrated environment has been developed. An edge-based rigid-body tracker is used in an observer-based controller, and combined with a six-degree-of-freedom force- or impedance controller.

Figure 5.11 shows three simultaneous views of an experiment with feedback from the multi-camera system and from a force sensor for robot controlled contour following. The tracking system has superimposed frame-boxes (red and green) around the tool.

## Real-Time Control

### Admission Control in Communication Networks

*Researchers: Anders Robertsson, Dan Henriksson, and Björn Wittenmark, in cooperation with Maria Kihl and Mikael Andersson, Department of Communication Systems, LTH, and with Tarek Abdelzaher, Ying Lu, and Ronghua Zhang, University of Virginia*

The admission control mechanism is an important part of many communication systems to avoid overload.

In this project we investigate the discrete-time modeling of a server system. Based on the nonlinear system model, we also design admission controllers and analyze the closed loop stability. An other important aspect is the verification of the server model behavior with respect to queue theoretic models.

Server systems typically contains non-linearities such as saturations and bounded queue lengths. The incoming traffic and service rates are best modeled by stochastic processes, well described and analyzed by queuing theory. A control theoretic model of a general single server queue, a so-called G/G/1-system, has been analyzed and validated.

Further, experimental evaluation is performed on an Apache web server in a laboratory network. A traffic generator is used to represent client requests. The control of the Apache server has been re-written to implement different algorithms. We show that the control theoretic model aligns well with the experiments on the web-server and that the controlled system behaves well. Measurements in the laboratory setup show the robustness of the implemented controller, and how it corresponds to the results from the theoretical analysis and the simulations.

**Center for Applied Software Research (LUCAS)**

*Researchers: Karl-Erik Årzén, Rolf Johansson, Anders Robertsson, Anton Cervin, Dan Henriksson, Bo Lincoln, Magnus Gäfvert, Martin Andersson, Anders Blomdell, Leif Andersson, in collaboration with Department of Computer Science and Department of Communications Systems*

The Center for Applied Software Research (LUCAS) is a collaboration between the software-oriented parts of three departments at LTH:

- Computer Science,
- Communication Systems, and
- Automatic Control.

In total around 15 faculty members and 20 PhD students are involved in LUCAS.

The focus of LUCAS is industrially-oriented and motivated software research. This includes research on software engineering, software technology, and software applications. Special focus is put on real-time systems, in particular embedded systems, networked systems, and control systems. The work is organized along three thematic areas:

- Software Engineering Environments
- Methods in Software Engineering
- Real-Time Systems Software

The first thematic area focuses on the core areas of integrated environments (tools and methods), object-oriented languages in the tradition of Simula, Beta, and Java, and embedded systems. The research method is focused on experimental implementation and development of relevant theory. Examples of issues that are studied are configuration management, collaboration support, domain-specific languages, frameworks and patterns and Java for embedded systems. The second thematic area is focused on software development processes, methods and architectural issues for development and maintenance of complex software systems. More specifically, the research is directed towards the following key areas: software quality, verification and validation,

requirements engineering, and software process architectures. The research is approached through empirical studies to understand, assess, and improve software development. The third thematic area is focused on the software aspects of real-time systems, in particular embedded system, networked systems, and control systems. Some examples of topics within the area are real-time kernels and run-time systems for embedded systems, system architectures for real-time control systems in, e.g. industrial automation and robotics, integrated approaches to control design and CPU and communication bandwidth scheduling, and verification and validation of real-time systems.

The activities within LUCAS consist of research projects in collaboration with industry, center activities, and teaching activities. The projects can span the full range of LUCAS or be focused on one of the thematic areas. The aim of the center activities is to maintain the infrastructure of LUCAS and to disseminate information among the partners. The teaching activities include both graduate-level courses and continued education courses.

Industries can join LUCAS at three levels of participation. A gold member is involved in projects over the full range of LUCAS and has a long-term strategic interest in the activities of LUCAS. Silver participants are involved in a single research project, whereas bronze members have access to the LUCAS network in terms of seminars, tutorials, courses, and workshops. During 2003 Sony Ericsson Mobile, and ABB Automation Technology Products were gold members. Silver members were Q-Labs, Telelogic, and Ericsson Microwave.

### Integrated Control and Scheduling

*Researchers: Anton Cervin, Dan Henriksson, Anders Blomdell, Bo Lincoln and Karl-Erik Årzén, with Teleca as the industrial node*

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 sub-projects: “Feedback Scheduling” undertaken by the Department of Automatic Control, Lund University, and “Flexible Automatic Memory Management” performed by the Department of Computer Science, Lund University. The real-time software

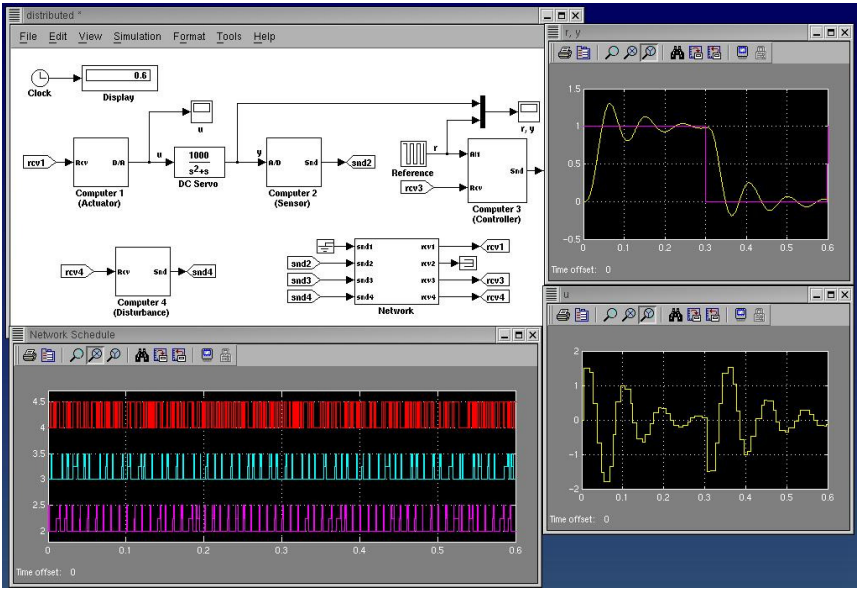



**Figure 5.12** Screenshot of the `TrueTime` simulator.

consulting company Teleca is the industrial ARTES node associated with the project. The project finances two ARTES PhD students, Anton Cervin at Automatic Control, and Sven Gestegård Robertz at Computer Science. The PhD student Dan Henriksson is also contributing to the project.

During 2003, which was last year in this project, the development of the MATLAB/Simulink-based real-time control systems simulator `TrueTime` was continued. `TrueTime` allows co-simulation of continuous process dynamics and multi-tasking real-time kernels and communication networks. TrueTime is event-based, written in C, and allows the user tasks to be defined as M functions, C functions, or Simulink diagrams, see `http://www.control.lth.se/~dan/truetime`

The MATLAB-based analysis tool `Jitterbug` was also further developed during the year. `Jitterbug` allows evaluation of a quadratic

performance criterion for a control loop under various timing conditions. The tool is quite general and can be used to investigate the effect of jitter, delay, aborted computations, etc., on control performance. The software can be downloaded from `http://www.control.lth.se/~lincoln/jitterbug`

The main event in the project during 2003 was the PhD dissertation by Anton Cervin. Most of the activities in the project will be continued within the new Flexcon project.

**FLEXCON: Flexible Embedded Control Systems**

*Researchers: Dan Henriksson, Martin Andersson, Anders Blomdell, Anton Cervin, and Karl-Erik Årzén, in collaboration with Department of Computer Science at Lund University, DAMEK at KTH, MRTC at Mälardalen University, and DRTS at University of Skövde*

Control and automation systems constitute an important subclass of embedded real-time systems. Control systems have traditionally been relatively static systems. However, technology advances and market demands are rapidly changing the situation. The increased connectivity implied by Internet and mobile device technology will have a major impact on control system architectures. Products are often based on commercial-off-the-shelf (COTS) components. The rapid development of component-based technologies and languages like Java and C# increases portability and safety, and makes heterogeneous distributed control-system platforms possible. The evolution from static systems towards dynamic systems makes flexibility a key design attribute for future systems.

FLEXCON is an SSF/IT research programme between January 2003 - December 2005. The budget is 10 MSEK. The key challenge of FLEXCON is how to provide flexibility and reliability in embedded control systems implemented with COTS component-based computing and communications technology. Research will be performed on design and implementation techniques that support dynamic run-time flexibility with respect to, e.g., changes in workload and resource utilization patterns. The use of control-theoretical approaches for modeling, analysis, and design of embedded systems is a promising approach to control

uncertainty and to provide flexibility, which will be investigated within FLEXCON. Other focal points are quality-of-service (QoS) issues in control systems, and testing-based verification and monitoring of flexible embedded control systems. The main application area is adaptive industrial automation systems. An industrial robotics-based demonstrator will serve as the carrier of the project results.

FLEXON is structured in five work packages:

- **WP1: Flexibility in real-time embedded control systems using COTS platforms, languages and components**
  The rapid development of COTS component-based computing and communications platforms lacking stringent timing guarantees makes static system designs based on worst-case assumptions increasingly conservative. Research is needed on design and implementation techniques that allow dynamic run-time flexibility with respect to, e.g., changes in workload and resource utilization patterns. In addition it is necessary to improve the understanding of how this dynamic flexibility may be combined with more traditional real-time system approaches based on static design approaches. For example, how should event-driven execution be combined with pre-scheduled time-driven execution in embedded control systems?

- **WP123: Control-based and Quality-of-Service approaches in embedded control systems**
  Using control-based approaches for modeling, analysis, and design of embedded computer and communications systems is currently receiving increased attention from the real-time systems community, as a promising foundation for controlling the uncertainty in large and complex real-time systems. Areas of growing interest include feedback architectures for adaptive real-time computing, theory for performance guarantees under uncertainty, integrated resource scheduling and feedback control, control-theoretical models of dynamic real-time systems, application of control theory for controlling timing behavior, and optimal, robust, or adaptive feedback control in real-time systems. The use of a control-based approach has the potential to increase flexibility, while preserving

dependability and efficiency. For example, control techniques can be used to compensate for shortcomings and imperfections in the implementation platforms. Control approaches to resource allocation are especially interesting for distributed control systems. For example, a feedback scheduler can distribute the computing and communications resources in such a way that the global control performance, or Quality-of-Control (QoC), is maximized. QoC is also an alternative approach to increasing dependability, e.g., through dynamic reconfiguration of resources in critical situations or for graceful degradation. The hypothesis for this work package is that flexibility in complex distributed feedback control systems can be achieved by developing a new and innovative concept for automatic negotiation of resources between control tasks based on new and appropriate measures of control quality. The overall idea is similar to the quality-of-service (QoS) concept developed for multi-media applications, but the means for estimating the achieved level of control, as well as timing requirements and resource structures are very different here. Hence, very few of the specific mechanisms and methods developed for QoS are applicable in QoC.

- **WP4: Testing-based verification and monitoring of flexible embedded control systems.**
  Testing-based verification of flexible real-time control systems is inherently hard. Besides testing in the value domain it is also necessary to test real-time systems in the time domain. Furthermore, the flexibility offered in event-driven real-time systems require substantially more test cases for complete test coverage than a corresponding time-triggered system. From an industry perspective, research in the testing area is interesting, as there are reports stating that as much as 50% of the resources spent in software development projects can be linked to testing activities. The requirement for third-party testing of COTS components also poses a challenge. Event monitoring in such systems can support continued testing as well as performance evaluation efforts. In safety-critical control applications, the need for rigid verification is high.

- **WP: Robotics and Automation Demonstrator.**
  In addition to publication of scientific results, we will confront those results with industrial aspects in an experimental setup. Apart from adding a focus to all of the workpackages, the demonstrator makes results more tangible and applicable for industry and applied research. Because of their needs for flexibility and safety in combination with needs for efficient real-time solutions and programming on several levels, robots comprise the most challenging case for flexible control. The focus here is not on robotics as such; the aim is to experimentally verify mechanisms and systems solutions for flexible embedded systems. Special emphasis will be put on dynamic deployment of control components, including testing and performance evaluation. This must be supported via host simulation, virtual models, and system access over the Internet. The physical robots and the necessary industrial experience for such a demonstrator are already available in the group, and results will be made available to other related projects. Hence, supporting this project is a golden opportunity to improve applicability of real-time systems research results.

Our department is involved in WP23 and WP5. Karl-Erik Årzén is also the program director for FLEXCON. An industrial advisory board consisting of members from ABB Robotics, ABB Automation Products, ABB Corporate Research, and Enea, supervise the progress of the project.

### Hard Real-Time CORBA for Control

*Researchers: Karl-Erik Årzén, Dan Henriksson, Anton Cervin, Johan Eker, Anders Blomdell in cooperation with Klas Nilsson, Mathias Haage, and Christian Andersson, Dept. of Computer Science, Lund Institute of Technology*

The Hard Real-Time CORBA for Control (HRTC) project is a one-year EU IST FP5 project with the aim to extend the application areas of the distributed object and component technology CORBA to also include hard real-time applications, e.g., networked control loops. The other partners in the project are Universitat Politecnica de Madrid, TU Vienna, and SCILabs.

The approach taken is to provide a deterministic pluggable transport layer that provides bounded network latencies. Two paths are followed. In one approach the time-triggered protocol TTP/C is used. In Lund we instead base the transport on scheduled switched Ethernet using the Throttlenet approach, developed at the Department of Automatic Control.

The results of the project has been demonstrated in two test-beds: an industrial robotics test-bed implemented in Lund and a process control testbed implemented in Madrid. The project was completed 1 October 2003.

## Biomedical Systems

### Biomedical Modeling and Control

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

The project is directed towards assessment of normal and pathological human postural control. System identification and mathematical modeling of the dynamics in postural control are studied with special interest on adaptation, reflexive and anticipatory control. Reflexive and voluntary eye movements are studied in patients with lesions related to balance disorders. Experimental studies, with special reference to the level of alertness, are undertaken to enhance understanding, diagnosis and treatment of dizziness and vertigo. A major complication is that human postural control is characterized by multi-sensory feedback control (visual, vestibular, proprioceptive feedback) and this fact is reflected both in experiment design and analysis. Special interest is directed to the importance of cervical and vestibular afference. To this purpose, stability properties are studied by means of induced perturbations specific to each sensory feedback loop by using system identification methodology. The work is supported by the Swedish Research Council and the Faculty of Medicine, Lund University.

### Cardiologic Analysis and Modeling

*Researchers: Rolf Johansson in cooperation with Prof. Bertil Olsson, and Jonas Carlson, M.Sc. (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 organized activation were identified. The nature of the organized activation suggested re-entry in an anatomical structure, like the right annular bundle surrounding the tricuspid valve. In patients without signs of organized 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.

## Automotive Systems

### Closed-loop Control of an Homogeneous Charge Compression Ignition (HCCI) Combustion Engine

*Researchers: J. Bengtsson, B. Johansson(+), R. Johansson, J.O. Olsson(+), P. Strandh(+), and P. Tunestål (+) (+)Div. Combustion Engines, Department of Heat and Power Engineering, Lund University*

Homogeneous Charge Compression Ignition is a hybrid of the spark ignition and compression ignition engine concepts. As in an SI engine, a homogeneous fuel-air mixture is created in the inlet system. During the compression stroke the temperature of the mixture increases and reaches the point of auto ignition, just as in a CI engine. One challenge with HCCI engines is the need for good timing control of the

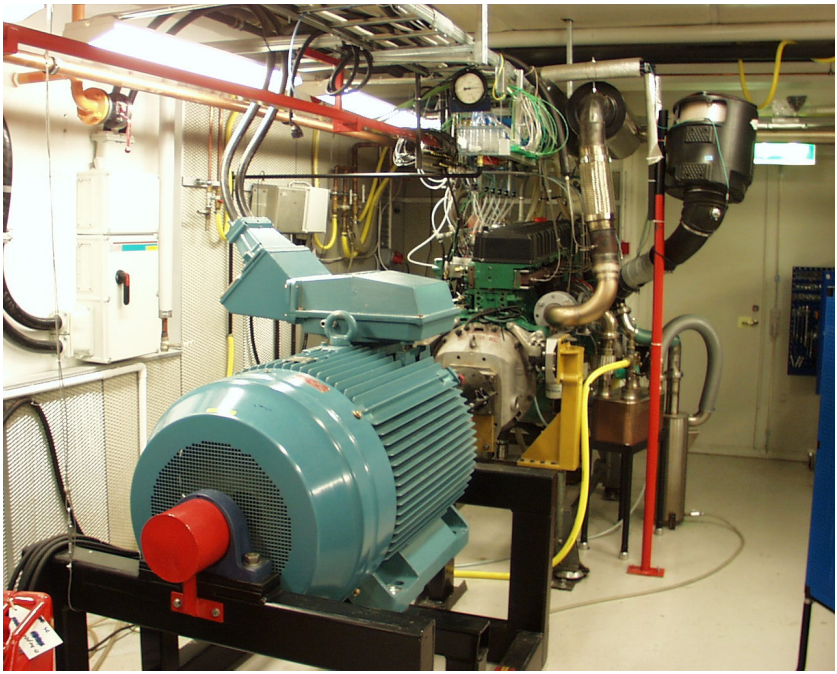


**Figure 5.13** Experimental set-up for HCCI engine control

combustion. Auto ignition of a homogeneous mixture is very sensitive to operating condition. Even small variations of the load can change the timing from too early to too late combustion. Thus, a fast combustion timing control is necessary since it sets the performance limitation of the load control. This project deals with various approaches to feedback control of the HCCI engine for optimized fuel economy and low emissions. A 12-liter Volvo Diesel engine has been successfully converted to HCCI operation with feedback systems based upon feedback of measured cylinder pressure or ion current. Since May 13, 2003, pressure-based feedback control is operative.

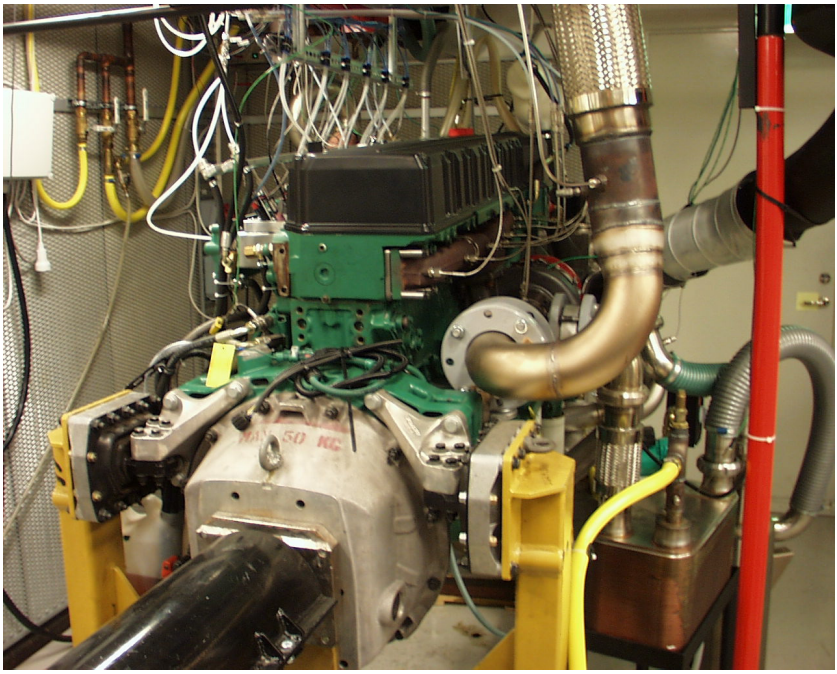


**Figure 5.14** The HCCI motor converted from a 12-liter Volvo Diesel Engine

### Natural Field Oriented Control (NFO) for Control of Induction Motor Drives

*Researcher: Rolf Johansson in cooperation with Ragnar Jönsson and Ove Glenberg, NFO Control AB, Lund*

The AC induction motor has been the workhorse in industry for more than 100 years, and it is still the dominating motor type in all areas of applications. However, it is non-trivial to control this motor and conventional frequency inverter are not sufficient for precision control. Moreover, classical frequency inverters are based on U/f-inverters with poor performance, especially at low motor speeds. Demonstration of high-performance AC induction motor as servomotor using vectorial control was first made by Blaschke in Prof. W. Leonhard's team in Braunschweig, Germany.

Natural Field Orientation (NFO) is a 'sensorless vector control system' for the AC induction motor, i.e. a feedback control that does not rely on sensors of mechanical quantities such as velocity or position. Historically, it has been difficult to combine vector control with sensorless operation. NFO stands for vector control with "Natural Field Orientation" where the two words "field orientation" tell that the control signals are oriented in relation to the magnetic field inside the motor. The word "natural" tells that the control principle is simple and intuitive. The patented NFO scheme generates control signals and trusts that the motor generates a correct field. The current project aims towards higher control performance of DSP-implemented NFO control in induction motor drive applications. The project is supported by Vinnova.

### Gas Turbine Combustion Stability

*Researchers: Rolf Johansson, Martin A. Kjaer in cooperation with CECOST (Dr. Jens Klingmann, Prof. Tord Torisson) and Siemens*

Today's strict environmental regulations are resulting in increasingly higher demands for more efficient gas turbines that provide ever lower emissions levels. This has lead to a continuous development of methods and concepts for competitive and robust combustors. In LPP (Lean Premixed Prevaporised) combustion the incoming fuel is mixed prior to combustion with the air stream delivered by the compressor. The

fuel is diluted by the air and hence the heat release is distributed in a bigger volume which results in lower local flame temperatures and thus less formation of NOx. The lower temperatures in the primary combustion zone make it more difficult to sustain a stable combustion during transients and part load operation. It is therefore desirable to control the combustion process during operation actively with respect to certain characteristic stability parameters. This project is supported by Siemens and Volvo Aero.

**Modeling of automotive combustion engines for Toyota**

*Researchers: Magnus Gäfvert, Oskar Nilsson, Anders Rantzer, in cooperation with Department of Heat and Power Engineering, Division of Combustion Engines.*

This is a project supported by Toyota Motor Company. The project was initiated after a sequence of mutual visits by Dr. Akira Ohata from Toyota Motor Company and Prof. Anders Rantzer from Lund University. It was preceded by a smaller project during 2002, where Hubertus Tummescheit developed models for oxygen sensors in the language Modelica. The current project has two components:

***Model validation/calibration for exhaust gas oxygen sensors***

This component builds on the work by Tummescheit and the purpose is to verify and improve the model quality by comparing simulations to measurements. It is also desirable to better understand of how various model parameters influence the behavior of the model.

Oxygen sensors, or lambda sensors, are core components in the emission control in modern SI stoichiometric engines. The performance of catalysts are highly dependent on exhaust gas composition and, e.g., the presence of oxygen needs to be precisely controlled. To meet future emission legislations it is required to refine and extend current lambda control strategies. Good understanding of catalyst operation is essential to improve emission performance. It is necessary to understand the interaction of the catalyst and the lambda control system, including the lambda sensors, to optimize the exhaust gas treatment. Physically based simulation models are then vital tools to analyze and evaluate

new control strategies. An important part in this is the sensor models, and their ability correctly reproduce effects of significance to catalyst operation. Of particular interest is the shift in voltage characteristics with respect to oxygen concentration that is observed when the exhaust gas is diluted with hydrogen or carbon Monoxide.

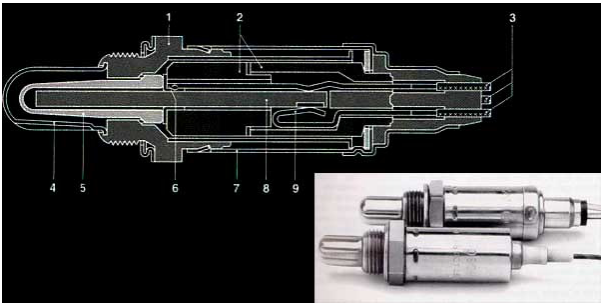



**Figure 5.15** A $\lambda$-sensor is used to measure the oxygen content in exhaust gases. This feedback signal is needed for proper operation of the catalyst

***Development of control design models for an HCCI engine*** Here the purpose of modeling is to support feedback control of the combustion timing in an HCCI engine. The models are developed in Modelica and include thermodynamics and simple thermo chemistry.

In homogeneous charge compression ignition (HCCI) engines the ignition timing is defined by the autoignition properties of the air-fuel mixture in use. The autoignition process is determined by chemical kinetics influenced by species concentrations and temperature trace. Small variations in the cylinder environment may greatly influence the ignition timing. Therefore, HCCI engines require precise control to operate with predictable timing and one major difficulty with HCCI engines is to control the moment of autoignition and the energy release rate. In order to arrive at successful control strategies it is necessary to have good models and substantial understanding of the ignition and combustion process. This project task aims at describing the major thermodynamic and chemical interactions in the course of an engine

stroke and their influence on ignition timing. Common strategies for timing control includes variable valve timing, variable compression ratio, or to employ varying the inlet temperature and fuel composition.

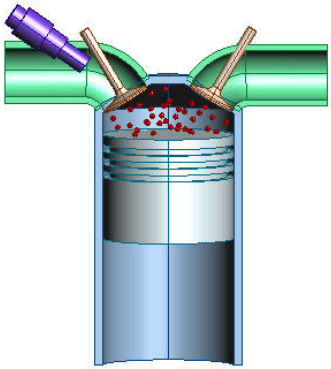


**Figure 5.16** A $\lambda$-sensor is used to measure the oxygen content in exhaust gases. This feedback is needed for proper operation of the catalyst

## Tire Models for Control and Friction Estimation

*Researchers: Jacob Svendenius, Haldex Brake Products AB and LTH, and Björn Wittenmark, in cooperation with Haldex Brake Products AB*

The future trend for brake systems seems to be a change to the use of electrical power in control and actuation instead of pneumatics. Using electrical brakes will not only result in a faster and more controllable system. It will also introduce new needs of adjustment and safety thinking. The brake system is one of the most critical systems in the vehicle and new and different disturbances that can risk the safety will occur. The possibility of faster and more accurate control of the brake actuator has also led to a need of better knowledge of the vehicle system. The entire system does not only incorporate the electro-mechanical components and the dynamics of the vehicle. Even changeable factors as the driving conditions and the adhesion between the tire and the

road has to be included. To be able to adjust for different conditions there is a need of adaptive control laws and identification of uncertain parameters. This has lead the project into modeling of the tire and its interaction with the road. The main aspect is how to estimate the adhesion limit for the tire and road surfaces and how it changes for different circumstances, for example, when the driver both turns and brakes at the same time.

### Tire Models for Braking Control

*Researchers: Jacob Svendenius, Magnus Gäfvert, and Björn Wittenmark in cooperation with Haldex*

The future trend for brake systems seems to be a change for use of electrical power in control and actuation instead of pneumatics. Using electrical brakes will not only result in a faster and more controllable system. It will also introduce new needs of adjustment and safety thinking. The brake system is one of the most critical systems in the vehicle and new and different disturbances that can risk the safety will occur. The possibility of faster and more accurate control of the brake actuator has also aroused a need of better knowledge of the vehicle system. The entire system does not only incorporate the electro mechanical objects and the dynamics of the vehicle. Even changeable factors as the driving conditions and the adhesion between the tire and the road has to be included. To be able to adjust for different conditions there is a need of adaptive control laws and identification of uncertain parameters. This has lead the project into modeling of the tire and its interaction with the road. The main aspect is how to estimate the adhesion limits for the tire and road surfaces and how it changes for for different circumstances, for example when the driver turns and brakes at the same time.

Accurate tire models are necessary components of models aimed at analyzing or simulating vehicle motion in real driving conditions. With new active chassis-control systems that are based on unilateral braking it is increasingly important to describe the effects of combined braking and cornering correctly. A new easy-to-use tire-force model aimed at simulation of vehicle dynamics is developed for this purpose. The model is based on combining empirical models for pure braking and cornering

with brush-model tire mechanics.

### Control of Antilock Braking Systems

*Researchers: Stefan Solyom and Anders Rantzer*

The Antilock Braking System is an important component of the complex steering system of a modern car. The first ABS systems were implemented in the late 70's, the main objective of the control system being prevention of wheel-lock. Most of ABS controllers available on the market are table and relay-feedback based, making use of hydraulic actuators to deliver the braking force. In the latest generation of "brake by wire" systems, electro-mechanic actuators are capable of delivering continuously varying and different brake forces independently to the four wheels. The control objective shifts to maintain a specified tire slip rather then just preventing wheel-lock. The set-point slip is supposed to be provided by a higher level in the hierarchy, (e.g., an ESP system), and can be used for stabilizing the steering dynamics of the car while braking. This might imply different slip reference values for each wheel.

It turns out that the slip control task is not trivial, one of the main reasons being the high amount of uncertainty involved. Most uncertainty arises from the friction between the tires and the road surface. In addition, the tire-road characteristics is highly nonlinear. A special problem arises due to potential fast change in surface conditions while braking, (e.g., a wet spot on a dry surface).

Within this project, we have developed a gain scheduled PI controller, based on tire-slip value, velocity over ground and the maximum friction coefficient, (i.e. friction coefficient at the top of the friction curve). This enables the controller to adapt to various fast changing road conditions. The controller robustly stabilizes the system for different slopes of the friction curve. Furthermore, it tolerates the time variations due to the decreasing velocity over ground of the car.

Tests have been carried out in a Mercedes E220 vehicle, Figure 5.17, provided by DaimlerChrysler, equipped with electro-mechanical brakes and brake-by-wire system.

The controller described above achieved the shortest braking distance of all controllers tested in the vehicle and outperformed the ABS used in series production.

**Figure 5.17** Test vehicle for the H2C project

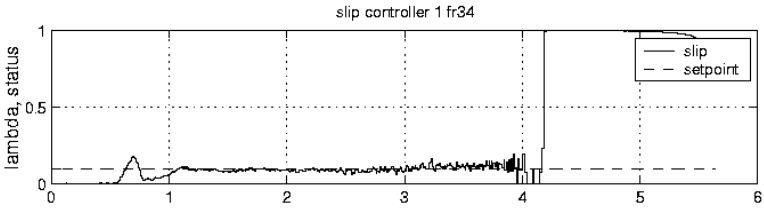



**Figure 5.18** Test result for an emergency braking on dry asphalt (slip vs. time [$s$]). The longitudinal tire slip is depicted while braking from an initial velocity of $30 m/s$ until standstill is achieved.

# 6. External Contacts

The role 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,
Alfa Laval AB,
Computas,
Corus,
DaimlerChrysler,
Ericsson Microwave,
Ericsson Mobile Platforms,
Gensym Corp.,
Haldex Brake Products AB,
IFP,
KCL,
KPS Rinas,
Kranendonk Production Systems BV,
NFO Control AB,
Novozymes,
Pfizer, Strängnäs,
Q-labs,
Scania CV AB,
SCILabs,
Siemens,
Sony Ericsson Mobile,
Thales,
Teleca,
Telelogic,
Tetra Pak Research & Development,
Toyota Motor Company,
UPM-Kymmene,
Volvo Aero,

Volvo Car Corporation,
Volvo Technical Development,
Volvo Trucks,
Volvo Powertrain,

We have had smaller projects with

Axis Communication,
M-real Husum AB,
and meetings and discussions with many other companies.

## European Collaboration

The department has been involved in eight applications to the 6th frame program of the European Commission. The following five were selected for contract negotiations:

***Networks of Excellence (NoE):***

- ARTIST2 — Embedded Systems Design
- HYCON — Hybrid Control: Taming heterogeneity and complexity of networked embedded systems
- EURON-II — The EU robotics network membership agreement

***Integrated Projects (IP):***

- RUNES — Reconfigurable Ubiquitous Networked Embedded Systems

***Specific Targeted Research Projects (STREP):***

- CEMACS — Complex Embedded Automotive Control systems

# 7. Dissertations

5 PhD theses were defended by Ari Ingimundarson, Anton Cervin, Magnus Gäfvert, Sven Hedlund, and Bo Lincoln; and 4 Licentiate theses were completed by Ola Slätteke, Jacob Svendenius, Dan Henriksson, and Johan Åkesson.

The abstracts are presented here in chronological order. PDF-documents of the theses are available at http://www.control.lth.se/publications/.

### Dead-Time Compensation and Performance Monitoring in Process Control

Ari Ingimundarson
PhD dissertation, January 31, 2003

*Opponent: Prof. Sten Bay Jørgensen, Department of Chemical Engineering, DTU, Denmark. Committee: Prof. Claes Breitholtz, Dept. of Signals and Systems, Chalmers, Gothenburg, Sweden; Prof. Gustaf Olsson, Dept. of Industrial Electrical Engineering and Automation, Lund Institute of Technology, Lund, Sweden; Dr. Stefan Rönnbäck, Optimation AB, Luleå, Sweden.*

The thesis contains two parts, dead-time compensation and performance monitoring. The first part on dead-time compensation is about robust tuning procedures for dead-time compensating controllers (DTC). Both stable and integrating processes are considered. Simple experiments are performed to obtain process models as well as bounds on the allowable bandwidth for stability. The DTCs used have few parameters with clear physical interpretation so that manual tuning is possible.

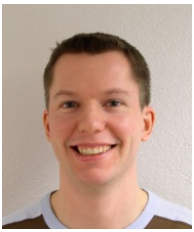
In the second part on dead-time compensation the performance of PID controllers is compared to the performance of DTCs. The aim is to answer the question: "When can a simple dead-time compensator be expected to perform better than a PID?". The performance criterion

used is the integrated absolute error (IAE). It is compared for PI and PID controllers and a simple dead-time compensator (DTC) when a step load disturbance is applied at the plant input.

The topic of the second part of the thesis is performance monitoring of lambda-tuned feedback controllers. A lambda-tuned loop is a loop with an one-degree-of freedom controller whose set point response is of first order plus dead time. Lambda is the time constant of the set-point response. For these loops a non intrusive performance monitoring methods is described which is thought to be a first indicator of bad performance after which existing diagnosis algorithms could be applied. For online implementation in distributed control systems a simple recursive algorithm to estimate the index is presented. All parameters of the monitoring method are set by using the lambda tuning. The method applies equally to stochastic or deterministic disturbances.

Finally an algorithm to estimate a synthetic gradient of a quadratic cost function is presented. It is demonstrated that the gradient can provide valuable information for maintenance of controllers as the gradient gives information about the disturbances affecting the loop.

### Integrated Control and Real-Time Scheduling



Anton Cervin
PhD dissertation, April 25, 2003

*Opponent: Prof. Martin Törngren, Royal Institute of Technology, Stockholm, Sweden. Committee: Prof. Giorgio Buttazzo, University of Pavia, Italy; Prof. Karl Henrik Johansson, Royal Institute of Technology, Stockholm, Sweden; Dr. Sven Erik Mattsson, Dynasim AB, Lund, Sweden.*

The topic of the thesis is co-design of flexible real-time control systems. Integrating control theory and real-time scheduling theory, it is possible to achieve higher resource utilization and better control performance. The integration requires new tools for analysis, design, and implementation.

The problem of scheduling the individual parts of a control algorithm is studied. It is shown how subtask scheduling can reduce the input-output latency in a set of control tasks. Deadline assignment under different scheduling policies is considered.

A feedback scheduling architecture for control tasks is introduced. The scheduler uses feedback from execution-time measurements and feedforward from workload changes to adjust the sampling periods of a set of control tasks so that the combined performance of the controllers is optimized.

The Control Server, a novel computational model for real-time control tasks, is presented. The model combines time-triggered I/O with dynamic, reservation-based task scheduling. The model provides short input-output latencies and minimal jitter for the controllers. It also allows control tasks to be treated as scalable real-time components with predictable performance.

Two MATLAB-based toolboxes for analysis and simulation of real-time control systems have been developed. The Jitterbug toolbox evaluates a quadratic cost function for a linear control system with timing variations. The tool makes it possible to investigate the impact of delay, jitter, lost samples, etc., on control performance. The TrueTime toolbox facilitates detailed cosimulation of distributed real-time control systems. The scheduling and execution of control tasks is simulated in parallel with the network communication and the continuous process dynamics.

**Topics in Modeling, Control, and Implementation in Automotive Systems**

Magnus Gäfvert
PhD dissertation, May 9, 2003

*Opponent: Prof. Andrew Alleyne, Univ. of Illinois at Urbana-Champaign, USA. Committee: Prof. Lars Nilsson, LiTH, Linköping, Sweden; Dr. Jan Wikander, Damek, KTH, Stockholm, Sweden; Prof. Ebbe Lundgren, Mechanics, LTH, Sweden.*

This thesis treats different aspects of automotive control-systems and consists of four papers covering different areas in this large field. The first paper presents a 9-degree-of-freedom dynamic model of a tractor-semitrailer vehicle, aimed at simulation and evaluation of active chassis-systems for stability enhancements. Special focus is put on inclusion of the dynamics of load transfer, which are of importance in active yaw-control and roll-over prevention.

The second paper presents a new easy-to-use, semi-empirical tire model for combined-slip conditions. The model is based on combining the standard rigid-carcass brush model with available empirical pure-slip models. A new method is presented for partitioning empirical pure-slip forces into components of sliding and adhesive forces.

The third paper regards control of gasoline direct injection engines. Strategies based on feedback of the effective torque are shown to relax the requirements of accurate engine maps, in simulations. It is exemplified that extremum control may be used for online optimization of the engine operation with respect to fuel consumption. A new control structure that combines the extremum controller with disturbance rejection is used, to render the probing signals of the optimizing controller invisible in the engine output.

The fourth paper presents a new method to limit the effects of transient faults, occurring in hardware that hosts implementations of feedback controllers. The idea is to introduce artificial signal limits that are

based on closed-loop signal bounds, and combine them with an anti-windup scheme.

### Dynamic Programming and Time-Varying Delay Systems

Bo Lincoln
PhD dissertation, May 17, 2003

*Opponent: Prof. P R Kumar, Univ. of Illinois, Urbana, IL, USA. Committee: Prof. Fredrik Gustafsson, ISY, Linköping University, Linköping, Sweden. Prof. Glenn Vinnicombe, Control Laboratory, University of Cambridge, England. Dr. Fredrik Dahlström, Ericsson Mobile Platforms, Lund, Sweden. Prof. Tobias Rydén, Mathematical Statistics, LTH, Lund, Sweden.*

This thesis is divided into two separate parts. The first part is about Dynamic Programming for non-trivial optimal control problems. The second part introduces some useful tools for analysis of stability and performance of systems with time-varying delays.

The two papers presented in the first part attacks optimal control problems with finite but rapidly increasing search space. In the first paper we try to reduce the complexity of the optimization by exploiting the structure of a certain problem. The result, if found, is an optimal solution.

The second paper introduces a new general approach of relaxing the optimality constraint. The main contribution of the paper is an extension of the Bellman equality to a double inequality. This inequality is a sufficient condition for a suboptimal solution to be within a certain distance to the optimal solution. The main approach of solving the inequality in the paper is value iteration, which is shown to work well in many different applications.

In the second part of the thesis, two analysis methods for systems with time-varying delays are presented in two papers. The first paper presents a set of simple graphical stability (and performance) criteria when the delays are bounded but otherwise unknown. All that is needed to verify stability is a Bode diagram of the closed loop system. For more

exact computations, the last paper presents a toolbox for Matlab called Jitterbug. It calculates quadratic costs and power spectral densities of interconnected continuous-time and discrete-time linear systems. The main contribution of the toolbox is to make well known theory easily applicable for analysis of real-time systems.

### Computational Methods for Optimal Control of Hybrid Systems

Sven Hedlund
PhD dissertation, May 26, 2003

*Opponent: Prof. Richard Vinter, Dept of Electrical and Electronic Engineering, Imperial College of Science, Technology and Medicine, London, England. Committee: Prof. Torkel Glad, Dept. of Automatic Control, Linköping University, Linköping, Sweden. Prof. Gustaf Söderlind, Numerical Analysis, Mathematical Statistics, Lund University, Lund, Sweden. Dr. Ulf Jönsson, Division of Optimization and Systems Theory, KTH, Stockholm, Sweden. Dr. Anders Holst, Centre for Mathematical Sciences, Lund University, Lund, Sweden.*

This thesis aims to find algorithms for optimal control of hybrid systems and explore them in sufficient detail to be able to implement the ideas in computational tools. By hybrid systems is meant systems with interacting continuous and discrete dynamics. Code for computations has been developed in parallel to the theory.

The optimal control methods studied in this thesis are global, i.e., the entire state space is considered simultaneously rather than searching for locally optimal trajectories. The optimal value function that maps each state of the state space onto the minimal cost for trajectories starting in that state is central for global methods. It is often difficult to compute the optimal value function of an optimal control problem, even for a purely continuous system. This thesis shows that a lower bound of the value function of a hybrid optimal control problem can be found via convex optimization in a linear program. Moreover, a dual of this optimization problem, parameterized in the control law, has been formulated via general ideas from duality in transportation

problems. It is shown that the lower bound of the value function is tight for continuous systems and that there is no gap between the dual optimization problems.

Two computational tools are presented. One is built on theory for piecewise affine systems. Various analysis and synthesis problems for this kind of systems are via piecewise quadratic Lyapunov-like functions cast into linear matrix inequalities. The second tool can be used for value function computation, control law extraction, and simulation of hybrid systems. This tool parameterizes the value function in its values in a uniform grid of points in the state space, and the optimization problem is formulated as a linear program. The usage of this tool is illustrated in a case study.

**Steam and Condensate System Control in Paper Making**

Ola Slätteke
Licentiate dissertation, October 14, 2003

*Opponent: Alf Isaksson, ABB Corporate Research, Västerås, Sweden.*

This thesis deals with various aspects of the modeling and control of the steam pressure in a cylinder dryer. It begins with a short motivation of the work and gives a description of the paper drying process. The different control loops and measuring principles are explained. Also, a few references are specified for further reading about subjects not treated in this text.

Modeling of the steam pressure is thoroughly discussed. Two types of models, a black-box and a grey-box, are presented. Both possess the same dynamical structure, but have different purposes. The intention for the black-box model is purely controller tuning. The main purpose of the grey-box model is to gain insight into the physical laws behind the black-box model. A grey-box model can also be used for fault detection and in connection with mechanical design of the dryers. An identification procedure for the black-box model is given and a few properties of the model are analyzed. In addition, the justification of the model itself is discussed.

The thesis also considers the control of the steam pressure. A set of control tuning rules is developed. The tuning rules are based on load disturbance rejection in connection with a robustness constrain and it has one design parameter which is defined by the user. To calculate the controller parameters, the method also requires the four process parameters from the black-box model, obtained from the identification procedure. The advantage with the method is that the equations are simple and it is easy to use.

### Tire Models for Use in Braking Applications

Jacob Svendenius
Licentiate dissertation, November 21, 2003

*Opponent: Prof. Staffan Nordmark, Statens väg- och transportforskningsinstitutet, Linköping, Sweden.* The tire is a significant part for control of a vehicle. For a well-working brake system the contact properties between the tire and the ground is the limiting factor for a safe braking. To get optimal performance it is important that the system can utilize all friction resources.

The brush tire model was a popular method in the 1960's and 1970's before the empirical approaches became dominating. The brush model gives an educational interpretation of the physics behind the tire behavior and explains that a part of the tire surface in the contact patch to the ground slides on the road surface. Information about the friction coefficient is revealed in the tire behavior even when low tire forces are transmitted. If the the brush model is sufficiently good it is possible to estimate the friction coefficient.

In the thesis the influence of velocity-dependent friction and asymmetric pressure-distribution on the brush model are examined. The latter is used to introduce a calibration factor to improve the agreement of the model to real data. Performed vehicle tests show that sufficient accuracy might be obtained.

The coupling between the longitudinal and lateral tire forces is discussed in detail and a new proposal to derive the combined slip forces from pure slip models is presented. This method relies on the physics from the brush model and includes a velocity dependency which is derived from the pure slip models. All information is extracted automaticly from the models, which allows continuous changes of the tire characteristics. The method shows good agreement to real data.

**Flexible Scheduling Methods and Tools for Real-Time Control Systems**

Dan Henriksson
Licentiate dissertation, December 12, 2003

*Opponent: Dr. Ola Dahl, Malmö University, Malmö, Sweden.*

This thesis deals with flexibility in the design of real-time control systems. By dynamic resource scheduling it is possible to achieve on-line adaptability and increased control performance under resource constraints. The approach requires simulation tools for control and real-time systems co-design.

One approach to achieve flexibility in the run-time scheduling of control tasks is feedback scheduling, where resources are scheduled dynamically based on measurements of actual timing variations and control performance. An overview of feedback scheduling techniques for control systems is presented.

A flexible strategy for implementation of model predictive control (MPC) is described. In MPC, the control signal in each sample is obtained by the solution of a constrained quadratic optimization problem. A termination criterion is derived that, unlike traditional MPC, takes the effects of computational delay into account in the optimization. A scheduling scheme is also described, where the MPC cost functions being minimized are used as dynamic task priorities for a set of MPC tasks.

The MATLAB/Simulink-based simulator TrueTime is presented. TrueTime is a co-design tool that facilitates simulation of distributed real-time control systems, where the execution of controller tasks in a real-time kernel is simulated in parallel with network transmissions and the continuous-time plant dynamics. Using TrueTime it is possible to study the effects of CPU and network scheduling on control performance and to experiment with flexible scheduling techniques and compensation schemes. A general overview of the simulator is given and the event-based kernel implementation is described.

TrueTime is used in two simulation case studies. The first emulates TCP on top of standard Ethernet to simulate networked control of a robot system. The second case study uses TrueTime to simulate a web server application. A feedback scheduling strategy for QoS control in the web server is described.

### Operator Interaction and Optimization in Control Systems

Johan Åkesson
Licentiate dissertation, December 15, 2003

*Opponent: Dr. Mikael Lundh, ABB Industrial Systems, Västerås, Sweden.*

The two themes of this thesis are operator interaction and optimization, primarily with application to complex plants in the process industry. Four important aspects that should be considered in the control system design for such plants are identified; safety, performance, operator interaction, and operator acceptance. In particular, operator acceptance is considered as an aspect of major importance. Since the operators are usually responsible for the operation of the plant, it is essential that the control system is well understood and accepted by the operators.

The inverted pendulum serves as introduction and motivating example of this thesis. In this application, the trade-off between safety and performance is important, in combination with close operator interaction.

A frame work for grade changes is presented. The proposed method integrates the use of a tool for sequential control, JGrafchart, and a method for dynamic optimization. It is shown how a simple parameterization of the control variable trajectories may be implemented and executed as a Grafcet sequence.

Model Predictive Control (MPC) is an optimization-based control strategy which has won widespread use in the process industry. In this thesis, tools for simulation and analysis of an MPC controller for linear systems are presented. The tools are used to investigate the effects of computational delay, and a method for delay reduction is proposed.

A method for ensuring offset-free tracking in centralized control of MIMO-systems is presented. It is shown how a particular choice of disturbance model can be used to prove that an observer-based controller will contain integral action. Specifically, the case where the number of measured variables exceeds the number of inputs is treated.

# 8. Honors and Awards

**Karl Johan Åström** was elected to the Process Control Hall of Fame.

**Anton Cervin** and **Johan Eker** were given the *Best Paper Award* for their paper "The Control Server: A computational model for real-time systems" at the 15th Euromicro Conference on Real-Time Systems in Porto, Portugal.

**Per Hagander** received the distinction *Excellent Teaching Practice (ETP)*.

**Rolf Johansson** As from November 14 appointment as *Visiting Professor* at the North China University of Science and Technology (NCUST), Taiyuan, Shanxi, China.

**Henrik Sandberg** got a scholarship from Institut Mittag-Leffler to cover for housing and increased living expenses during his 5 months stay at the institute.

# 9. Personnel and Visitors

## Personnel

During 2003 the following persons have been employed at the department. The list shows the *status of December 2003* if nothing else is mentioned.

**Professors**

Karl-Erik Årzén
Karl Johan Åström (emeritus)
Bo Bernhardsson *(on leave from May 2001)*
Per Hagander
Tore Hägglund
Rolf Johansson
Anders Rantzer
Björn Wittenmark

**Associate Professor**

Anders Robertsson

**Researchers**

Anton Cervin *(from May)*
Magnus Gäfvert *(from June)*
Bo Lincoln *(from June)*

**Research Engineers**

Leif Andersson
Anders Blomdell
Rolf Braun

**PhD Students**

Johan Åkesson
Peter Alriksson *(from June)*
Martin Andersson *(from February)*
Johan Bengtsson
Anton Cervin *(until April)*
Lena de Maré
Jenny Ekvall
Magnus Gäfvert *(until May)*
Ather Gattami *(from June)*
Ove Glenberg *(until June)*
Sven Hedlund *(until May)*
Staffan Haugwitz
Dan Henriksson
Ari Ingimundarson *(until January)*
Martin A. Kjær *(from June)*
Bo Lincoln *(until May)*
Oskar Nilsson *(from June)*
Pontus Nordfeldt *(from June)*
Rasmus Olsson
Tomas Olsson
Mikael Petersson
Henrik Sandberg
Brad Schofield *(from June)*
Ola Slätteke
Stefan Solyom
Jacob Svendenius
Stéphane Velut
Andreas Wernrud *(from February)*

**Secretaries**

Britt-Marie Mårtensson
Eva Schildt
Agneta Tuszyński

## Visiting Scientists

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

**Chung-Yao Kao** *August 22, 2002–January 15, 2003*
MIT, Cambridge, USA

**Ricardo Rojas Reischel and Son Christian** *February 16–February 20, 2003*
Universidad Técnica Federico Santa Maria, Valparaiso, Chile

**Anton Shiriaev** *February 24–February 28 and June 23–June 27, 2003*
Umeå University, Umeå, Sweden

**Tadeusz Kaczorek** *April 9–April 10, 2003*
Politechnika Warszawska, Warsaw, Poland

**Andrew Alleyne** *March 30–April 6 and May 8–May 9, 2003*
University of Illinois, USA

**Giorgio Buttazzo** *April 24–April 25, 2003*
University of Pavia, Pavia, Italy

**Panganamala R. Kumar** *May 15–May 20, 2003*
University of Illinois, USA

**Glenn Vinnicombe** *May 16–May 18, 2003*
University of Cambridge, England

**Arthur Krener** *May 21–May 22, 2003*
UC Davis, California, USA

**Richard Vinter** *May 25–May 26, 2003*
Imperial College, England

**Graham Goodwin** *May 27–June 2, 2003*
The University of Newcastle, Callaghan, Australia

**Javier Gamez García** *June 1–September 15, 2003*
Universidad Jaén, Jaén, Spain

**Garatti Simone** *July 25–August 25, 2003*
Politecnico di Milano, Milano, Italy

**Tariq Samad** *September 11–September 13, 2003*
Honeywell Automation and Control Solutions, Minneapolis, USA

**Doug Looze** *September 12, 2003*
University of Massachusetts, USA

**Lui Sha** *September 25–September 27, 2003*
University of California, USA

**Joaquin Collado** *October 20–October 24, 2003*
Cinvestav, Mexico City, Mexico

**David Hill** *October 20–October 22, 2003*
City University Hong Kong, China.

## Visiting Students

The following foreign students have stayed with the department and followed courses. Many of them have made their master's theses. The students are from the ERASMUS program.

**Francesco Angerosa** *until May 2003*
Universita degli studi di Napoli "Federico II", Italy

**Samuel Kasper** *until June 2003*
Eidgenössiche Technische Hochschule Zürich, Switzerland

**Gerard Duffin** *until June 2003*
Imperial College of Science, Technology and Medicine, GB

**Xavier Callier** *until June 2003*
Institut des Sciences de la Matiere et du Rayonnement, France

**Erik Casagrande** *until June 2003*
Universita degli studi di Padova, Italy

**Alessandro Bindi** Universita degli studi di Firenze, Italy

**Marta Virseda** *from October 2003*
Universidad de Valladolid, Spain

**Isolde Dressler** *from October 2003*
Technische Universität München, Germany

**Ana Llorente** *from October 2003*
Universidad de Zaragoza, Spain

**Marcel Meerstetter** *from January 2003*
Eidgenössische Technische Hochschule Zürich, Switzerland

**Francesco Vivoli** *from October 2003*
Universita degli studi di Firenze, Italy

**Davide Malagoli** *from October 2003*
Universita degli studi di Firenze, Italy

# 10. 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, Johan**

Lic Tech, graduate student since January 2001. Johan's main research interest is in the field of decision support structures for chemical process industry, specifically systems for operator support during grade changes. During 2003 he was working in the EC project CHEM. Johan's research interests also include stabilization of unstable systems subject to input saturation. During 2003, Johan was a teaching assistant in the courses Real Time Systems and System Identification.

**Alriksson, Peter**

MSc graduate student since June 2003. His research interests are in estimation and optimal control of hybrid systems. In particular, he is interested in using optimal estimation for fault detection. Peter has also been supervising the International Project Course in cooperation with Ecole de Mines, Nantes, France.

**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, Martin**

Msc, graduate student since September 2003. Martins research interests concern design and analysis of realtime control systems, and he is involved in ARTES++. During the fall Martin has been teaching assistant in the Real-Time Systems course.

**Årzén, Karl-Erik**

Professor (2000), PhD (1987): Joined the department in 1981. His research interests are real-time control, real-time systems, programming languages for control, Petri nets and Grafcet, and monitoring and diagnosis.

Project leader for the SSF/ARTES project on integrated control and scheduling and the SSF/FLEXCON project on flexible embedded control systems. Member of the steering committee of LUCAS (Center for Applied Software Research). During the year he has personally primarily been involved in the EU CHEM project on decision support systems for the process industries, the EU HRTC project on Hard Real-Time CORBA for control, and in the SSF/FLEXCON project. He has been responsible for and taught the undergraduate course on Real-Time Systems and the International Project Course in Automatic Control. He is partly or fully involved in the supervision of five PhD students.

**Åström, Karl Johan**

Professor since 1965, Emeritus from 2000. He founded the department and has broad interests in control including physical modeling, PID control, switched and adaptive systems. This year he has worked on a book on PID control with Tore Hägglund and he improved the control curriculum with development of new lecture notes. He has also participated in the Panel Future Directions in Control. Dynamics and Systems supported by the Airforce Office of Scientific Research (AFOSR). The panel report was published by SIAM and a summary appeared in the IEEE Control Systems Magazine, April 2003. In March he participated in the applied mathematics program at the Mittag-Leffler Institute.

**Bengtsson, Johan**

Lic Tech in November 2001, graduate student since April 1999. He is interested in applying controls engineering to Homogeneous Charge Compression Ignition (HCCI) Engines, system identification, modeling and visual servoing. He is currently working in cooperation with Volvo cars, Volvo Technical Development and SAAB Scania on modeling and control of a 6-cylinder HCCI engine. During the year he has been teaching assistant in Computer-Controlled Systems.

**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 languages for control engineering.

During the year, Linux has successfully been deployed for robot control in the Autofett project, and a first implementation of the ThrottleNet protocol has been done in the HRTC project.

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 (now mainly used in m680x0 and PowerPC systems). A closely related project is the Modula-2 to C translator used in the real-time research and education at the department.

**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**

PhD in April 2003, joined the department in 1998. Anton's research topic is real-time systems, and he did his thesis work within the ARTES/SSF project "Integrated Control and Scheduling". This year, Anton, together with Johan Eker, has been working on a novel

computational model for real-time control systems, called the Control Server. He has also been working within the project HRTC (Hard Real-Time CORBA for Control), developing a simulation model of switched ethernet for the TrueTime simulator. On the teaching side, he developed and lectured the new course "Control for InfoCom" (a basic course in control for the Information and Communication Engineering students).

**de Maré, Lena**

MSc, graduate student since August 1999. She is interested in control of biotechnical processes and is working together with Stéphane Velut and Per Hagander in the project 'Process control for cultivation of genetically modified micro-organisms' funded by Vinnova. During 2003 a collaboration together with O. Holst at the Biotechnology Department at LTH and G. Silfversparre at Novozymes Biopharma AB on temperature-limited fed-batch cultivations with *E. coli* has taken place. Another project on how to control a complex feed into a bioreactor has started together with C. Cimander at Novozymes Biopharma AB. During 2003 she has been a teaching assistant in Automatic control, basic course, Systems Engineering and in Computer-Controlled systems.

**Ekvall, Jenny**

Graduate student since January 2002. Jenny's main research interest is in the field of monitoring and supervision. Her present project is control and supervision at grade changes, in collaboration with M-real, Husum. The process she studies is the drying section of a paper machine. Jenny is employed by Mid Sweden University and she is part of the research group NPI (Network for Process Intelligence) in Örnsköldsvik, where she also has her office.

**Gäfvert, Magnus**

PhD in Automatic Control (2003), MSc in Engineering Physics (1996) followed by graduate studies at the department, Researcher. Magnus is interested in modeling and control in automotive applications. Recent work include the areas of engine control, vehicle dynamics, and safety-critical systems. Further interests include aspects of implementation

of control systems. Previous work also regard modeling, analysis and control of systems with friction. During the year he has finished his PhD, and continued work on HCCI engine modeling in collaboration with Toyota Motor Corporation. He was also responsible for the course on Process Control and assistant teacher in the International Project Course. He was advisor for Master's Thesis works and various student projects. Magnus is involved in the development and support of the computer based interactive tools for control education, ICTools.

**Gattami, Ather**

Ather Gattami has been a PhD student at the Department of Automatic Control since September 2003. His Research interests are analysis and controller design of interconnected and complex systems. He has been a teaching assistant and project supervisor for the Adaptive Control course.

**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. Per is the LTH vice rector of international affairs. During 2003 he taught Systems Engineering (W). He is leading a project with Pfizer AB, on multivariable control of genetically engineered E. Coli. The work is also a collaboration with the Department of Biotechnology, Lund University and SBL Vaccine. A new project on the control of a special type of continuous chemical reactors was started together with Alfa Laval AB within the Center for Process Design and Control (CPDC).

**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). 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 controllers, and research projects in collaboration with the pulp and paper industry.

**Haugwitz, Staffan**

MSc, graduate student since August 2002. Staffan is working with Per Hagander on the project "Control of a Open Plate Reactor", which is funded by Alfa Laval AB and CPDC. The project is run by Alfa Laval in collaboration with several other universities and institutes in Sweden and in France. During the spring Staffan was teaching assistant in the Nonlinear Control course for undergraduates.

**Henriksson, Dan**

Lic Tech in December 2003, graduate student since December 2000. Dan's research interests concern design and analysis of real-time control systems, and he is involved in the SSF/ARTES++ project "Flexible Embedded Control Systems" (FLEXCON). During 2003 Dan has been teaching assistant in Computer-Controlled Systems and Real-Time Systems.

**Johansson, Rolf**

Professor, MD, PhD. Active at the department since 1979. Rolf Johansson's research interests are in system identification, robotics and nonlinear systems and automotive control. He is coordinating director for Robotics Laboratory with cooperation partners from Dept Computer Science, Dept Mechanical Engineering and industrial partners. He has industrial cooperation with ABB Robotics, NFO Control AB, Siemens, Volvo Powertrain, Volvo Car Corporation and Scania CV AB. He is responsible for the two courses FRT041 System Identification and FRT050 Adaptive Control. Together with Dr. Måns Magnusson he leads research at the Vestibular Laboratory, Dept. Otorhinolaryngology, Lund University Hospital. During 2003, he made invited research visits to University of Newcastle, New South Wales, Australia and Tsinghua University, Beijing, China.

**Mårtensson, Britt-Marie**

Secretary at the department since 1974. She is responsible for the department library, ordering books, handles the mail and office supplies. Assistant Webmaster. She handles the contact with printing offices for dissertations and other publications. Britt-Marie is also the department's service-person.

**Nilsson, Oskar**

Graduate student since September 2003. Oskar is currently working on physical system modeling together with Anders Rantzer and Magnus Gäfvert in a project funded by Toyota. During the autumn he has been teaching assistant in the Automatic Control Basic Course.

**Nordfeldt, Pontus**

MSc. Graduate student since September 2003. His research interest is in decoupling and automatic tuning of TITO systems. The work has been focused on decoupling. Pontus has been teaching assistant in the basic Automatic Control course. He has also been working in a project with TetraPak and B&R.

**Olsson, Rasmus**

Lic Tech in December 2002, graduate student since August 1999. Rasmus area of research is batch control, and he is part of the CPDC graduate school. His focus has been on exception handling in recipe-based batch control. During 2003 he has been teaching assistant in the undergraduate courses Automatic Process Control, Automatic Control Basic Course, and Real-Time Systems.

**Olsson, Tomas**

MSc, graduate student since December 2001. His main research interests are robotic force control, visual servoing, and observer-based visual position tracking. He has been working with applications of force control in the EU project Autofett. During the year Tomas has been a teaching assistant in the courses in Automatic Control and Real-Time Systems.

**Petersson, Mikael**

Graduate student since 1997. Petersson holds a position at the Automation Technology division of ABB as an industrial PhD-student. His research interests is in control loop performance monitoring of industrial processes, and applying and evaluating advanced theory in this area.

The research has been focused on assessing the control structure based on measurements and particular work has been carried out on feedforward control structure, with one patent approved, cascade control, and gain scheduling.

**Rantzer, Anders**

Professor of Automatic Control since 1999. Joined the department in 1993 after a PhD at KTH 1991 and a post-doc position at IMA, University of Minnesota. He has broad interests in modeling, analysis and synthesis of control systems, with particular attention to computational methods for uncertainty, nonlinearities and hybrid phenomena.

Anders Rantzer is department chairman and was the main supervisor for seven PhD students in 2003. Two of them, Hedlund and Lincoln, finished their PhD dissertations during the year. Rantzer also served on several committees within the university. He gave a semi-plenary lecture at the European Control Conference 2003 in Cambridge. He served on several editorial boards and professional committees and one evaluation board for the Swedish Research Council.

**Robertsson, Anders**

Research Associate (May 2003), PhD (1999). His main interest is in nonlinear control and robotics. Currently he is working on sensor-data integration and force control of industrial robots in collaboration with ABB Robotics. The research has been conducted with the LUCAS project and the Robotics Lab. He has also been doing research on admission control systems in network nodes in cooperation with the Department of Telecommunications, LTH. He has lectured the course on Nonlinear Control and Servo Systems for engineering students, the PhD-course on Nonlinear Control Synthesis and acted as advisor for several Master's Thesis projects.

During the fall he made a short research visit with Prof. Anton Shiriaev at the Dept. of Applied Physics and Electronics, Umeå University.

**Sandberg, Henrik**

Lic Tech in November 2002, graduate student since January 2000. Henrik is interested in analysis, reduction, and control of periodic and time-varying systems. He is involved in the CPDC-project "Reduction and aggregation of process models" and the VR-project "Theory for modelling, control and analysis of periodic systems".

Henrik spent five months in 2003 at Institut Mittag-Leffler in Stockholm. During the year he has also been a teaching assistant in the course Adaptive Control.

**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 the personnel administration and takes care of the administration concerning visitors at the department.

On May 8, her grandchildren, Max and Ida, were born.

**Schofield, Brad**

M.Eng. (Imperial College London 2003). Graduate student since August 2003. His research interests include the application of subspace idenification methods in adaptive control. He has been a teaching assistant in the Automatic Control basic course as well as the Adaptive Control course. He will soon begin work on a project dealing with rollover detection and prevention in motor vehicles.

**Slätteke, Ola**

MSc, graduate student since January 2001. Employed by ABB Industries as an industrial PhD-student. His work is focused on modeling and control of the drying section of a paper machine within the CPDC-project. Ola also has a few years of experience of the pulp and paper industry, working at Stora Enso Nymölla AB as a control engineer.

**Solyom, Stefan**

MSc, graduate student since August 1999. His research interest is in nonlinear and hybrid control strategies. In particular, he is interested in piecewise linear systems. During the years he has worked on an Anti-lock Braking System within ESPRIT project H2C. There, tests have been carried out in cooperation with DaimlerChrysler. In 2002 he started working in a European project on Computation and Control (CC). He has also been teaching assistant in the courses Automatic Control (basic course), Adaptive Control.

**Svendenius, Jacob**

Lic Tech since november 2003 and MSc in mechanical engineering since 1998. He worked for three years in the laboratory at Haldex Brake Products with performance testing of brakes aimed for heavy vehicles. 2001 he started as a PhD student at the department in a project together with Haldex concerning braking control. During the spring 2003 he visited the department of automatic control at ENSIEG, Grenoble, France to work for Carlos Canudas de Wit on tire models.

**Tuszyński, 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 works with word processing in LaTeX. Agneta is also responsible for Activity Report 2003 together with Anders Robertsson.

**Velut, Stéphane**

MSc, graduate student since 1999. He is interested in extremum control and control of biotechnical processes. He is working together with Léna de Maré and Per Hagander in the project 'Process control for cultivation of genetically modified micro-organisms' funded by Vinnova. During 2003 a collaboration together with O. Holst at the Biotechnology Department at LTH and G. Silfversparre at Novozymes Biopharma AB on temperature-limited fed-batch cultivations with *E. coli* has taken place. During 2003 he has been a teaching assistant in Automatic control, basic course, Systems Engineering and Nonlinear Control.

**Wernerud, Andreas**

M. Sc., graduate student since March 2003. Andreas has developed a Matlab program together with a simple graphical user interface for control synthesis. He has also studied the controller reduction problem.

During the fall he was a teaching assistant in Automatic Control, basic course.

**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 currently working within projects in the area of process design and control and control of communication networks. Björn was also chairman of the department during until February 28, 2003.

## External Assignments

***Opponent and Member of Examination Committee***

Karl-Erik Årzén: Member of the examination board of the PhD thesis by Björn Andersson Dept of Computer Engineering, Chalmers Institute of Technology, Gothenburg, Sweden, Sep 29.

Karl Johan Åström: Opponent for Jacob Much, DTU, Lyngby, Denmark, July 3.. Opponent for Birgitta Christensson, Chalmers, Gothenburg, Sweden, August 29.

Per Hagander: Examination committee for Jing Liu, Biotechnology, LTH, Lund, Sweden.

Tore Hägglund: Faculty opponent on the PhD thesis by Jonas Öhr, Uppsala University, Sweden.

Rolf Johansson: Examination Committee Member on September 12, 2003 for dissertation of Henrik Malm, Studies in Robotic Vision, Optical Illusions and Nonlinear Diffusion Filtering, Dept. Mathematics, Lund University. Member of Ph. D. examination committee.

### *Board Member*

Karl-Erik Årzén: Member of the Board of SNART (Swedish National Association for Real-Time Systems). Member of the Education Board of Computer Engineering and Communications Engineering.

Tore Hägglund: Member of the Education Board of Engineering Physics, and the Appointment Board for FIME - physics, informatics mathematics and electrical both at Lund Institute of Technology. Expert member in legal proceedings for patent at Svea Court of Appeal, 2004–2006

Anders Rantzer: Member of the evaluation board on Signals and Systems at the Swedish Research Council. Member of the steering committee for the International Symposium on Mathematical Theory of Networks and Systems. Member of the scientific steering committee for the spring semester 2003 at the Institut Mittag-Leffler of The Royal Swedish Academy of Sciences.

Björn Wittenmark: Assistant vice-chancellor for Lund University from March 1, 2003. Chairman of the Board of Campus Helsingborg. Board member of LUCAS. Board member of IEEE Control Systems Society President and board member of the Royal Physiographic Society, Lund. Member of the Disciplinary Committee at Lund University. Expert member in legal proceedings for patent at Svea Court of Appeal, 2001-2003.

### *Book and Journal Editor*

Tore Hägglund: Associate editor for Control Engineering Practice.

Rolf Johansson: Assoc. Editor Int. J. Adaptive Control and Signal Processing.

Anders Rantzer: Member of the editorial board for International Journal of Robust and Nonlinear Control.

Björn Wittenmark: Member of Editorial Board: IEE Proceedings Control Theory & Applications, Optimal Control Applications & Methods, Journal of Forecasting, and International Journal of Adaptive Control and Signal Processing. Reviewer for research evaluations for the Swedish Research Council, Australian Research Council, Norwegian

Research Council, and Italian National Research Council. External reviewer of forest industry research at Karlstad University.

***Advisory Committees and Working Groups***

Karl-Erik Årzén: Vice Chairman of the IFAC Technical Committe on Computers and Control. Member of the IFAC Technical Committee on Chemical Process Control.

Per Hagander: Member of IFAC Technical Committee BIOMED. Member of IFAC Technical Committee Biotechnological Processes. ESBES - Working group $M^3C$.

Tore Hägglund: Member of IFAC Technical Committee on Adaptive and Learning Systems

Rolf Johansson: IEEE EMBS Technical Committee (TC) for Biomedical Robotics. IEEE TCST Outstanding Paper Award Committee.

Anders Rantzer: Member of IEEE CSS Tech. Com. on Nonlinear Systems and Control.

Björn Wittenmark: Chairman of the committee for IFAC Control Engineering Practice Price. Chairman IEEE Control System Society Distinguished Lectures Program *Distinguished Lectures Program of the IEEE Control System Society*.

***Member of International Program Committee (IPC)***

Karl-Erik Årzén: Member of the IPC for ADHS'03 (IFAC Conference of Analysis and Design of Hybrid Systems. Member of the IPC for the 15th Euromicro Conference on Real-Time Systems.

Per Hagander: Member of 5th IFAC Symposium on Modelling and Control in Biomedical Systems.

Tore Hägglund: Member of the International Program Committees for the conferences Control Systems 2004 in Quebec, Canada, Controlo 2004 - 6th Portuguese Conference on Automatic Control in Algarve, Portugal, DYCOPS 7 in Boston, 2004 IEEE Conference on Computer-Aided Control Systems Design (CACSD) in Taipei, Taiwan.

Rolf Johansson: EEE/ASME International Conference on Advanced Intelligent Mechatronics 2003 (AIM2003), Kobe, JAPAN, July 20-24, 2003. IEEE 2003 Int. Conference on Robotics and Automation (ICRA2003), Taipei, Taiwan, September 14-19, 2003. IFAC Symp. Advances in Automotive Control (AAC04), Salerno, Italy, April 19-23, 2004, April 2004. IEEE 2004 International Conference on Robotics and Automation (ICRA2004), New Orleans, LA, USA, April 26 - May 1, 2004. M2VIP2003 -Mechatronics and Machine Vision in Practice, Perth, Australia, December 2003.

Anders Rantzer: Member of IPC for European Control Conference 2003. Member of IPC for 4th IFAC Symposium on Robust Control Design (ROCOND-2003). Member of IPC for 6th Int. Workshop: Hybrid Systems: Computation and Control, 2003.

Björn Wittenmark: Member of the International Program Committee Member for ECC 2003, Cambridge and for Nordic Matlab Conference, Copenhagen, October 2003. Member of the Technical Committee for IFAC Adaptive Control and Learning. Member of the IEEE Control System Society Long-Range Planning Committee.

# 11. Publications and Conference Contributions

This year 4 books, 2 book contributions, 13 journal papers and 31 conference contributions have been published.

## Book

Åström, Karl Johan: *Harry Nyquist (1889–1976): A Tribute to the Memory of an Outstanding Scientist*. Royal Swedish Academy of Engineering Sciences, 2003. ISBN 91-7082-703-6.

Åström, Karl Johan, Stephen P. Boyd, R. W. Brockett, and G. Stein: *Control in an Information Rich World: Report of the Panel on Future Directions in Control, Dynamics, and Systems*. Society of Industrial and Applied Mathematics, Philadelphia, USA, 2003. ISBN 0-89871-528-8.

Johansson, Rolf, and Anders Rantzer: *Nonlinear and Hybrid Systems in Automotive Control*. Springer-Verlag, London, 2003. ISBN 1-85233-652-8.

Rantzer, Anders, and C. I. Byrnes: *Directions in Mathematical Systems Theory and Optimization*, vol. 286 of *LNCIS*. Springer-Verlag, Berlin Heidelberg, 2003. ISBN 3-540-00065-8.

## Book Contributions

Gäfvert, Magnus, Karl-Erik Årzén, Bo Bernhardsson, and Lars Malcolm Pedersen: "Control of gasoline direct injection engines using torque feedback: A simulation study." In Johansson and Rantzer, Eds., *Nonlinear and Hybrid Systems in Automotive Control*, pp. 289–320. Springer, May 2003.

Prajna, Stephen, and Anders Rantzer: "On homogeneous density functions." In Rantzer and Byrnes, Eds., *Directions in Mathematical Systems Theory and Control*, pp. 261–274. Springer Verlag, Berlin Heidelberg, 2003. ISBN 3-540-00065-8.

Solyom, Stefan, and Anders Rantzer: "ABS control—a design model and control structure." In *Nonlinear and Hybrid Systems in Automotive Control*, pp. 85–96. Springer Verlag, 2003.

## Journal Papers

Andersson, Sofia, Tobias Rydén, and Rolf Johansson: "Linear optimal prediction and innovations representations of hidden Markov models." *Stochastic Processes and their Applications*, **108:1**, pp. 131–149, 2003.

Askerdal, Örjan, Magnus Gäfvert, Martin Hiller, and Neeraj Suri: "Analyzing the impact of data errors in safety-critical control systems." *IEICE Transactions on Information and Systems*, **E86-D:12**, December 2003. Special Issue on Dependable Computing.

Carlson, Jonas, Susana Santos, Pyotr G. Platonov, Ole Kongstad Rasmussen, Rolf Johansson, and S. B. Olsson: "Left atrial conduction along the coronary sinus during ectopic atrial tachycardia and atrial fibrillation: A study using correlation function analysis." *Journal of Cardiovascular Electrophysiology*, **14:10**, pp. S148–S153, October 2003.

Cervin, Anton, Dan Henriksson, Bo Lincoln, Johan Eker, and Karl-Erik Årzén: "How does control timing affect performance?" *IEEE Control Systems Magazine*, **23:3**, pp. 16–30, June 2003.

de Maré, Lena, Lena Andersson, and Per Hagander: "Probing control of glucose feeding in *Vibrio cholerae* cultivations." *Bioprocess and Biosystems Engineering*, **25**, January, pp. 221–228, January 2003.

Fransson, Per-Anders, Anna Hafström, Mikael Karlberg, Måns Magnusson, Annika Tjäder, and Rolf Johansson: "Postural control adaptation during galvanic vestibular and vibratory proprioceptive stim-

ulation." *IEEE Transactions on Biomedical Engineering*, **50**, December, pp. 1310–1319, December 2003.

Fransson, Per-Anders, Rolf Johansson, Fredrik Tjernström, and Måns Magnusson: "Adaptation to vibratory perturbations in postural control." *IEEE Engineering in Medicine and Biology Magazine*, **22:2**, pp. 53–57, March 2003.

Gäfvert, Magnus: "Inte bara föraren styr." *RVF-Nytt (Tema transporter)*, **No 4**, pp. 18–19, October 2003.

Murray, Richard, Karl Johan Åström, Stephen P. Boyd, R. W. Brockett, and G. Stein: "Future directions in control in an information-rich world." *IEEE Control Systems Magazine*, **23:2**, pp. 20–33, April 2003.

Petersson, Mikael, Karl-Erik Årzén, and Tore Hägglund: "A comparison of two feedforward control structure assessment methods." *International Journal of Adaptive Control and Signal Processing*, **17:7–9**, pp. 609–624, August 2003.

Rantzer, Anders, and Sven Hedlund: "Density and cost in non-linear control." *European Journal of Control*, **9:2–3**, pp. 285–295, September 2003.

Solyom, Stefan, Anders Rantzer, and Jens Lüdemann: "Synthesis of a model-based tire slip controller." *Vehicle System Dynamics*, **41:6**, pp. 477–511, June 2004.

Strandh, Petter, Magnus Christensen, Johan Bengtsson, Rolf Johansson, Andreas Vressner, Per Tunestål, and Bengt Johansson: "Ion current sensing for HCCI combustion feedback." *SAE Paper 2003-01-3216*, **No 2003-01-3216**, October 2003.

## Conference Papers

Åkesson, Johan, and Per Hagander: "Integral action - a disturbance observer approach." In *Proceedings of European Control Conference*, September 2003.

Åkesson, Johan, and Per Hagander: "Kamratgranskning av rapporter i kursen systemteknik." In *Pedagogisk Inspirationskonferens*, pp. 47–49, May 2003.

Åkesson, Johan, and Anders Robertsson: "Muddiest point - erfarenheter och reflektioner," (Muddiest point - experiences and reflections). In *Pedagogisk Inspirationskonferens*, pp. 37–39, May 2003.

Alcocer, Alex, Anders Robertsson, A. Valera, and Rolf Johansson: "Force estimation and control in robot manipulators." In *7th Symposium on Robot Control (SYROCO'03), September 1-3*, pp. 31–36, Wroclaw, Poland, September 2003.

Andersson, Mikael, Maria Kihl, and Anders Robertsson: "Modelling and design of admission control mechanisms for web servers using non-linear control theory." In *Proceedings of Information Technologies and Communications (ITCom 2003)*, Orlando, Florida, USA, September 2003.

Årzén, Karl-Erik, Anton Cervin, and Dan Henriksson: "Resource-constrained embedded control systems: Possibilities and research issues." In *Proceedings of CERTS'03 – Co-design of Embedded Real-Time Systems Workshop*, Porto, Portugal, July 2003.

Bate, Iain, Peter Nightingale, and Anton Cervin: "Establishing timing requirements and control attributes for control loops in real-time systems." In *Proceedings of the 15th Euromicro Conference on Real-Time Systems*, Porto, Portugal, July 2003.

Calugi, Francesco, Anders Robertsson, and Rolf Johansson: "An adaptive observer for dynamical ship position control using vectorial observer backstepping." In *Proc. IEEE Conf. Decision and Control (CDC2003)*, December 2003.

Cervin, Anton: "Using Jitterbug to derive control loop timing requirements." In *Proceedings of CERTS'03 – Co-Design of Embedded Real-Time Systems Workshop*, Porto, Portugal, July 2003.

Cervin, Anton, and Johan Eker: "The Control Server: A computational model for real-time control tasks." In *Proceedings of the 15th Euromicro Conference on Real-Time Systems*, pp. 113–120, Porto, Portugal, July 2003. Best paper award.

Collado, J., R. Lozano, and Rolf Johansson: "Strictly positive real problem with observers." In *European Control Conference 2003 (ECC03), September 1-4, 2003*, Cambridge, England, September 2003.

Gäfvert, Magnus, Björn Wittenmark, and Örjan Askerdal: "On the effect of transient data-errors in controller implementations." In *Proc. of the American Control Conference*, pp. 3411–3416, Denver, Colorado, 2003.

Hagander, Per, Johan Åkesson, and Anders Robertsson: "Kamratgranskning av laborationsförberedelser i reglerteknik." In *Pedagogisk Inspirationskonferens*, pp. 62–64, May 2003.

Haugwitz, Staffan: "Modelling of microturbine systems." In *In Proceedings of European Control Conference*, September 2003.

Henriksson, Dan, Anton Cervin, and Karl-Erik Årzén: "TrueTime: Real-time control system simulation with MATLAB/Simulink." In *Proceedings of the Nordic MATLAB Conference*, Copenhagen, Denmark, October 2003.

Ingimundarson, Ari, Tore Hägglund, and Karl Johan Åström: "Criteria for design of pid controllers." In *Proceedings of the 2nd IFAC conference Control System Design, CSD'03*, Bratislava, Slovak Republic, 2003.

Ingimundarson, Ari, and Stefan Solyom: "On a synthesis method for robust PID controllers for a class of uncertainties." In *Proceedings of the European Control Conference, ECC'03*, Cambridge, UK, 2003.

Johansson, Rolf, and Anders Robertsson: "Robotic force control using observer-based strict positive real impedance control." In *Proceedings of the 2003 IEEE International Conference on Robotics and Automation*, pp. 3686–3691, Taipei, Taiwan, September 14-19, September 2003.

Kao, Chung-Yao, and Anders Rantzer: "Stability criteria for systems with bounded uncertain time-varying delay." In *Proceedings of European Control Conference*, September 2003.

Karlsson, Magnus, Ola Slätteke, Björn Wittenmark, and Stig Stenström: "Evaluation of models for the steam supply system." In *Tappi Spring Technical Conference & Trade Fare*, Chicago, May 2003.

Kihl, Maria, Anders Robertsson, and Björn Wittenmark: "Analysis of admission control mechanisms using non-linear control theory." In *Proceedings of IEEE Int Symp on Computer Communications (ICSS 2003)*, Kemer-Antalya, Turkey, June 2003.

Kihl, Maria, Anders Robertsson, and Björn Wittenmark: "Performance modelling and control of server systems using non-linear control theory." Berlin, Germany, September 2003. 18th International Teletraffic Congress.

Lincoln, Bo, and Anders Rantzer: "Relaxed optimal control of piecewise linear systems." In *Proceedings of the IFAC Conference on Analysis and Design of Hybrid Systems*, June 2003.

Olsson, Tomas, Johan Bengtsson, Anders Robertsson, and Rolf Johansson: "Visual position tracking using dual quaternions with hand-eye motion constraints." In *IEEE Int. Conference on Robotics and Automation*, pp. 3491–3496, Taipei, Taiwan, September 2003.

Rantzer, Anders, and Sven Hedlund: "Duality between cost and density in optimal control." In *Proceedings of the 42nd IEEE Conference on Decision and Control*, 2003.

Robertsson, Anders, Björn Wittenmark, and Maria Kihl: "Analysis and design of admission control in web-server systems." In *Proceedings of ACC'03*, 2003.

Shiriaev, Anton, Rolf Johansson, and Anders Robertsson: "Sufficient conditions for dynamical output feedback stabilization via the circle criterion." In *Proc. IEEE Conf. Decision and Control (CDC03)*, Maui, HI, December 2003.

Shiriaev, Anton, Anders Robertsson, and Rolf Johansson: "Friction compensation for passive systems based on the LuGre model." In *Proc. 2nd IFAC Workshop on Lagrangian and Hamiltonian Methods for Nonlinear Control,*, pp. 183–188, Seville, Spain, April 2003.

Solyom, Stefan: “A synthesis method for static anti-windup compensators.” In *Proceedings of the European Control Conference, ECC’03*, Cambridge, UK, 2003.

Svendenius, Jacob, and Björn Wittenmark: “Brush tire model with increased flexibility.” In *European Control Conference*, September 2003.

Velut, Stéphane, and Per Hagander: “Analysis of a probing control strategy.” In *American Control Conference*, 2003.

## Patent

Petersson, Mikael, Karl-Erik Årzén, and Tore Hägglund: “En metod och ett system för utvärdering huruvida en signal är lämplig för framkopplingsreglering (A method and a system for evaluation whether a signal is suitable for feed-forward control).” Swedish patent 0004171-S, 2003-07-01.

# 12. Reports

During this year 5 PhD theses and 4 Licentitate theses have been published. The abstracts are presented in Chapter 7. Also 18 Master theses and 7 internal reports have been completed.

## Dissertations

Åkesson, Johan: "Operator interaction and optimization in control systems." Technical Report Licentiate thesis ISRN LUTFD2/TFRT--3234--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, December 2003.

Cervin, Anton: *Integrated Control and Real-Time Scheduling*. PhD thesis ISRN LUTFD2/TFRT--1065--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, April 2003.

Gäfvert, Magnus: *Topics in Modeling, Control, and Implementation in Automotive Systems*. PhD thesis ISRN LUTFD2/TFRT--1066--SE, May 2003.

Hedlund, Sven: *Computational Methods for Optimal Control of Hybrid Systems*. PhD thesis ISRN LUTFD2/TFRT--1068--SE, Lund Institute of Technology, Sweden, May 2003.

Henriksson, Dan: "Flexible scheduling methods and tools for real-time control systems." Technical Report Licentiate thesis ISRN LUTFD2/TFRT--3233--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, December 2003.

Ingimundarson, Ari: *Dead-Time Compensation and Performance Monitoring in Process Control*. PhD thesis LUTFD2/TFRT 1064 SE, Lund Institute of Technology, Sweden, January 2003.

Lincoln, Bo: *Dynamic Programming and Time-Varying Delay Systems*. PhD thesis ISRN LUTFD2/TFRT--1067--SE, May 2003.

Slätteke, Ola: "Steam and condensate system control in paper making." Technical Report Licentiate thesis ISRN LUTFD2/TFRT-3231-SE, Department of Automatic Control, October 2003.

Svendenius, Jacob: "Tire models for use in braking applications." Technical Report Licentiate thesis ISRN LUTFD2/TFRT--3232--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, November 2003.

## Masterʹs Theses

Avergård, Pontus, and Fredrik Lindström: "Modelling of crankcase gas behaviour in a heavy-duty diesel engine." Technical Report Master's thesis ISRN LUTFD2/TFRT--5699--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, January 2003.

Bindi, Alessandro: "Iterative feedback tuning with application to robotics." Technical Report Master's thesis ISRN LUTFD2/TFRT--5715--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, December 2003.

Casagrande, Erik: "Dynamic vision shape from motion." Technical Report Master's thesis ISRN LUTFD2/TFRT--5707--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, June 2003.

Duffin, Gerard: "Kinematic analysis of rapid eye movements for vestibular disorders." Technical Report Master's thesis ISRN LUTFD2/TFRT--5705--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, June 2003.

Gattami, Ather: "Analysis of interconnected systems." Technical Report Master's thesis ISRN LUTFD2/TFRT--5720--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, August 2003.

Ghosh, Suvaudra: "Experimental analysis of virtual reality as a stimulus in posturography." Technical Report Master's thesis ISRN LUTFD2/TFRT--5704--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, June 2003.

Johansson, Niklas, and Tobias Folkesson: "Hastighetsreglering av monokromator (speed control of a monochromatic lens)." Technical Report Master's thesis ISRN LUTFD2/TFRT--5713--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, September 2003.

Kasper, Samuel: "Distributed real time robot vision in java." Technical Report Master's thesis ISRN LUTFD2/TFRT--5702--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, March 2003.

Kaunitz, Johan: "Multirate control of a dvd player." Technical Report Master's thesis ISRN LUTFD2/TFRT--5708--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, August 2003.

Lindberg, Mikael: "Optimizing yacht routes using dynamic programming." Technical Report, Department of Automatic Control, Lund Institute of Technology, Sweden, December 2003.

Lindholm, Max: "Side wind compensation using active suspension." Technical Report Master's thesis ISRN LUTFD2/TFRT--5714--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, October 2003.

Ljungkrantz, Oscar: "Steam net simulation with real control system." Technical Report Master's thesis ISRN LUTFD2/TFRT--5701--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, January 2003.

Nilsson, Oskar: "Physics based wave generation for the shallow water equations." Technical Report Master's thesis ISRN LUTFD2/TFRT--5710--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, August 2003.

Nilsson, Roger, and Mikael Nordgren: "Vision-based control of the overhead crane." Technical Report Master's thesis ISRN LUTFD2/TFRT--5712--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, September 2003.

Nordfeldt, Pontus: "Regulator design for a flexible servo." Technical Report Master's thesis ISRN LUTFD2/TFRT--5709--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, August 2003.

Pfeiffer, Roland: "Combustion control of the homogenous charge compression ignition dynamics." Technical Report Master's thesis ISRN LUTFD2/TFRT--5711--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, September 2003.

Schofield, Brad: "Subspace based identification for adaptive control." Technical Report Master's thesis ISRN LUTFD2/TFRT--5706--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, June 2003.

Ståhl, Fredrik: "Diabetes mellitus modelling based on blood glucose measurements." Technical Report Master's thesis ISRN LUTFD2/TFRT--5703--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, April 2003.

Trobro, Christian, and Mathias Magnusson: "Improving wheel speed sensing and estiamtion." Technical Report Master's thesis ISRN LUTFD2/TFRT--5716--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, December 2003.

## Other Reports

Cervin, Anton, and Bo Lincoln: "Jitterbug 1.1—Reference manual." Technical Report ISRN LUTFD2/TFRT--7604--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, January 2003.

Gäfvert, Magnus, and Jacob Svendenius: "Construction of novel semi-empirical tire models for combined braking and cornering." Technical Report ISRN LUTFD2/TFRT--7606--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, April 2003.

Hägglund, Tore, and Agneta Tuszynski: "Automatic control 2002. activity report." Technical Report ISRN LUTFD2/TFRT--4030--SE,

Department of Automatic Control, Lund Institute of Technology, Sweden, May 2003.

Henriksson, Dan, and Anton Cervin: "TrueTime 1.13—Reference manual." Technical Report ISRN LUTFD2/TFRT--7605--SE, Department of Automatic Control, Lund Institute of Technology, October 2003.

Iftime, Orest, Rien Kaashoek, Henrik Sandberg, and Amol Sasane: "Grassmannian approach to the hankel norm approximation problem." Technical Report ISRN IML-R--32-02/03--SE+spring, Institut Mittag-Leffler, The Royal Swedish Academy of Sciences, Stockholm, Sweden, 2003.

Sandberg, Henrik: "Frequency-domain analysis of linear time-periodic systems." Technical Report ISRN IML-R--29-02/03--SE+spring, Institut Mittag-Leffler, The Royal Swedish Academy of Sciences, Stockholm, Sweden, August 2003.

Svendenius, Jacob, and Björn Wittenmark: "Review of wheel modeling and friction estimation." Technical Report ISRN LUTFD2/TFRT--7607--SE, Department of Automatic Control, Lund Institute of Technology, Sweden, 2003.

## 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, 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

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The reports in the 1000- and 3000-series may be ordered from the Department, see address 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).

# 13. Lectures by the Staff Outside the Department

**Årzén, Karl-Erik**

*Resource-Constrained Embedded Control Systems: Possibilities and Research Issues,* Workshop on Co-design'of Embedded Real-Time Systems (CERTS'03), Porto, Portugal, July 1.

*Co-design of Resource-Constrained Embedded Control Systems,* Real-Time in Sweden Conference, Västerås, Sweden, August 18.

**Åström, Karl Johan**

*Lebesque Sampling and Pulsed Systems,* Tokyo University, Tokyo, Japan, February 24.

*Using bicycles in Control Education,* Tokyo Denku University, Tokyo, Japan, February 28.

*Control – the Hidden Technology,* Tokyo Denku University, Tokyo, Japan, February 28.

*Assessment of Achievable Performance,* Tokyo Institute of Technology, Tokyo, Japan, March 3.

*Svarta lådor och vitt brus (Black Boxes and White Noise),* The Royal Swedish Academy of Sciences (KVA), Stockholm, Sweden, March 12.

*Control - the Hidden Technology,* University of Michigan, Ann Arbor, USA, April 3.

*Feedback Fundamentals – A short lecture series,* University of Malaga, Malaga, Spain, June 23-25.

*Bicycles – A Mechatronic View,* Symposium on Mechatronics, Chalmers, Gothenburg, Sweden, August 28.

*Harry Nyquist - A tribute to the memory of an outstanding scientist,* Royal Swedish Academy of Engineering Science (IVA), Stockholm, Sweden, October 24.

**Cervin, Anton**

*Using Jitterbug to Derive Control Loop Timing Requirements,* Workshop on Co-design in Embedded Real-Time Systems, Porto, Portugal, July 1.

*The Control Server: A Computational Model for Real-Time Control Systems,* 15th Euromicro Conference on Real-Time Systems, Porto, Portugal, July 2.

*Co–Design of Real-Time Control Systems: The Control Server approach,* Real-Time in Sweden 2003, Västerås, August 18.

*Integrated Control and Real-Time Scheduling,* Invited lecture. Department of Electrical Engineering, Linköping Institute of Technology, Linköping, Sweden, October 9.

*Integrated Control and Real-Time Scheduling,* Invited lecture. Department of Systems, Signals, and Sensors, Royal Institute of Technology, Stockholm, Sweden, October 15.

**Gäfvert, Magnus**

*Tractor-Semitrailer Handling Modeling and Control of GDI Engines,* Invited lecture. Scania, Södertälje, Sweden, May 28.

*Topics in Modeling, Control, and Implementation in Automotive Systems,* Invited lecture. Department of Signals, Sensors & Systems, Royal Institute of Technology, May 28.

*On the Effect of Transient Data-Errors in Controller Implementations,* American Control Conference, Denver, CO, Jun 5.

*Control of GDI engines,* Invited lecture. University of Illinois at Urbana-Champaign, USA, Jun 10.

*A dynamic tractor-semitrailer handling model and issues on fault-tolerant automotive systems,* Invited lecture. Haldex Brake Products AB, Landskrona, Sweden, Jun 13.

**Hagander, Per**

*Kamratgranskning av laborationsförberedelser,* Pedagogisk inspirationskonferens, Lund, Sweden, May 27.

*Integral Action - A Disturbance Observer Approach,* ECC 03, Cambridge, September.

*Integral Action - A Disturbance Observer Approach,* UTFSM, Valparaiso, Chile, September.

*Research and Postgraduate Studies in Automatic Control,* UTFSM, Valparaiso, Chile, September.

*Probing Control of Substrate in Fed-batch Bacteria Cultures,* UTFSM, Valparaiso, Chile, September.

**Hägglund, Tore**

*Process Control in Practice,* Industrial course, Stockholm, Sweden, Jan 29–30.

*Process Control in Practice,* Industrial course, Stockholm, Sweden, March 4–5.

*Process Control in Practice,* Industrial course, Stockholm, Sweden, November 25–26.

**Haugwitz, Staffan**

*Modelling of Microturbine systems,* European Control Conference in Cambridge, UK, September 2.

**Henriksson, Dan**

*Simulation and Feedback Scheduling of Real-Time Control Systems,* Department of Computer Science, University of Virginia, Charlottesville, Virginia, USA, July 25.

*TrueTime: Real-Time Control System Simulation with MATLAB/Simulink,* Nordic MATLAB Conference, Copenhagen, Denmark, October 22.

**Johansson, Rolf**

*Mathematics & Medicine,* Department of Medicine, Lund University Hospital, Lund University, February 11, 2003.

*Human postural Control,* Royal Melbourne Institute of Technology and University of Melbourne, Melbourne, Victoria, Australia, March 21, 2003.

*Automotive Control,* Volvo Car Corporation, Gothenburg, Sweden, June 18, 2003.

*Observer–based Strict Positive Real (SPR) Feedback Control System Design,* University of Newcastle, Callaghan, NSW, Australia, July 11, 2003.

*Homogeneous Charge Compression Ignition (HCCI) Combustion Engines,* University of Newcastle, Callaghan, NSW, Australia, July 16, 2003.

*Observer–based Strict Positive Real (SPR) Systems,* China-Sweden Control Symposium, Stockholm, August 21, 2003.

*Robotic Force Control using Observer-based Strict Positive Real Impedance Control,* 2003 IEEE International Conference on Robotics and Automation, Taipei, Taiwan, September 18, 2003.

*Homogeneous Charge Compression Ignition (HCCI) Combustion Engines,* Tsinghua Univ., Beijing, China, November 5, 2003.

*Adaptive and Learning Control,* Shanghai Jiao Tong University, Shanghai, China, November 7, 2003.

*Automotive Control–Adaptive Cruise Control,* Shanghai Jiao Tong University, Shanghai, China, November 7, 2003.

*Computer-controlled Systems and Hybrid Systems,* Tsinghua Univ., Beijing, China, November 10, 2003.

*System identification–Subspace-based Model Identification,* Tsinghua Univ., Beijing, China, November 12, 2003.

*Observer-based Strict Positive Real (SPR) Feedback Control System Design,* Tsinghua University, State Key Laboratory of Control and Power Systems, Beijing, China, November 13, 2003.

*Automatic Control–Some Recent Trends,* North China University of Science and Technology (NCUST), Taiyuan, Shanxi, China, November 14, 2003.

*Robotics and Automotive Control,* Tsinghua Univ., Beijing, China, November 17, 2003.

*An Adaptive Observer for Dynamical Ship Position Control Using Vectorial Observer Backstepping,* IEEE Conf. Decision and Control (CDC2003), Maui, HI, December 11, 2003.

**Olsson, Tomas**

*Visual Position Tracking using Dual Quaternions with Hand-Eye Motion Constraints,* IEEE Int. Conference on Robotics and Automation, Taipei, Taiwan, September 18.

**Rantzer, Anders**

*Density and flow: A different view on nonlinear control,* Seminar at SUPELEC, Gif-sur-Yvette, Paris, January 16.

*On dissipation, density and decentralization,* Invited lecture at Institut Mittag-Leffler, Stockholm, April 9.

*Density and cost — duality in nonlinear and hybrid control,* Invited lecture at 14th International Workshop on Operator Theory and Applications, Cagliari, Italy, June 25.

*Hur styrs robotar och farkoster? — om matematiken bakom teknologin,* Invited lecture at Summer school in Mathematics, Kalmar, Sweden, Aug 11.

*Hybrid Control Synthesis using the Bellman Inequality,* Invited lecture at the Swedish-Chinese Control Conference, Stockholm, Sweden, August 22.

*Stabilization of nonlinear systems,* Semi-plenary lecture at European Control Conference, Cambridge, UK, September 2.

*Duality between cost and density in optimal control,* 42nd IEEE Conference on Decision and Control, Maui, Hawaii, USA, December 9.

**Robertsson, Anders**

*Using the Circle Criterion for Dynamic Output Feedback Control,* 1st Swedish-Chinese Conference on Control KTH, Stockholm, August 22.

*Force Estimation and Control in Robot,* Presentation at 7th Symposium on Robot Control (SYROCO'03), Wroclaw, Poland, September 2.

*Robotar och andra svårstyrda saker— Hur man får saker att bete sig som man vill,* Seminar at "Tekniska föreningen"/Kristianstad University, Sweden, March 4.

**Sandberg, Henrik**

*Balanced Truncation of Linear Time-Varying Systems,* Seminar. Invited by Dr. Ulf Jönsson. Optimization and Systems Theory, Royal Institute of Technology, Stockholm, Sweden, March 21.

*Balanced Truncation of Linear Time-Varying Systems,* Student seminar, Institut Mittag-Leffler, Stockholm, Sweden, April 15.

*Chemometrics and Model Reduction — What is the Connection?,* CPDC-workshop. Simrishamn, Sweden, August 20.

**Slätteke, Ola**

*Development of new Control Algorithms for the Drying Section,* Industrial seminar, Arlanda, Sweden, April 23.

*Control of the Drying Section of a Paper Machine,* Invited lecture at Skogsindustrins Utbildning, Sigtuna, Sweden, October 9.

**Solyom, Stefan**

*A Synthesis Method for Static Anti-Windup Compensators,* European Control Conference, Cambridge, UK.

*Voltage Stability in Power Systems,* Computation and Control (CC) project meeting, Siena, Italy.

**Wittenmark, Björn**

*Analysis and design of admission control in web-server systems,* American Control Conference, Denver, CO, June 5, 2003.

# 14. Seminars at the Department

Seminars presented in order of date. The seminars were given at the department during 2003, 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 20: **Fredrik Lindström, Pontus Avergård** (LTH), *Modelling of Crankcase Gas Behaviour in a Heavy-Duty Diesel Engine.* MSc-thesis presentation.

Jan 20: **Nicolas Andreff** (IFMA, Clermont-Ferrand), *Visual servoing from lines.*

Jan 21: **Nicolas Andreff** (IFMA, Clermont-Ferrand), *Vision-based calibration of parallel robots.*

Jan 21: **Xavier Callier** (IFMA, Clermont-Ferrand), *Robot modeling and code generation with Modelica.* MSc-thesis presentation.

Jan 28: **Oscar Ljungkrantz** (LTH), *Steam net simulation with real control system.* MSc-thesis presentation.

Jan 30: **Sten Bay Joergensen** (DTU Denmark), *Integration of Process and Control Design Through Model Analysis.*

Jan 31: **Ari Ingimundarson** (AC), *Dead-Time Compensation and Performance Monitoring in Process Control.* Doctoral dissertation defence.

Jan 31: **Tommaso Agnoloni** (University of Florence), *Switching Supervisory Control Based on Controller Falsification and Performance Inference.*

Feb 13: **Karl Johan Åström** (AC), *Using Bicycles in Control Education – How a Bike Really Works.*

Feb 18: **Ricardo A. Rojas Reischel** (Universidad Técnica Federico Maria, Chile), *The Inverse of Sampling Revisited.*

Feb 24: **Johan Kaunitz** (LTH), *Multirate control of a DVD player.* MSc-thesis presentation.

Mar 5: **Samuel Kaspar** (ETH), *Distributed Real Time Robot Vision in Java.* MSc-thesis presentation.

Mar 23: **Vance Carter** (National Instruments), *LabVIEW Control Design, Prototyping and Validation.*

Apr 1: **Andrew Alleyne** (University of Illinois), *Control of Systems in a Nondimensional Framework: Applications to Vehicle Control.*

Apr 1: **Fredrik Ståhl** (LTH), *Diabetes Mellitus Modelling using Blood Glucose Measurements.* MSc-thesis presentation.

Apr 2: **Andrew Alleyne** (University of Illinois), *MIMO Modeling and Control of a Novel Earthmoving Vehicle Powertrain.*

Apr 3: **Andrew Alleyne** (University of Illinois), *Injection Molding Machine Control: A Case Study in Control Engineering.*

Apr 24: **Tariq Samad** (Honeywell Laboratories), *From Automation to Autonomy: Implications for Software-Enabled Control.*

Apr 24: **Giorgio C. Buttazzo** (University of Pavia), *Real-time issues in energy-aware scheduling.*

Apr 25: **Anton Cervin** (AC), *Integrated Control and Real-Time Scheduling.* Doctoral dissertation defence.

May 9: **Magnus Gäfvert** (AC), *Topics in Modeling, Control, and Implementation in Automotive Systems.* Doctoral dissertation defence.

May 17: **Bo Lincoln** (AC), *Dynamic Programming and Time-varying Delay Systems.* Doctoral dissertation defence.

May 19: **P.R. Kumar** (University of Illinois), *Wireless networks: Ultimate limits, scaling laws, and optimal operation.*

May 19: **P.R. Kumar** (University of Illinois), *Wireless networks: Protocols, architecture, and towards convergence.*

May 22: **Art Krener** (UC Davis), *Control Bifurcations.*

May 26: **Sven Hedlund** (AC), *Computational Methods for Optimal Control of Hybrid Systems.* Doctoral dissertation defence.

May 26: **Richard Vinter** (Imperial College), *Differential Games and Controller Design: A Case Study in Process Control.*

May 27: **Graham Goodwin** (University of Newcastle) *Estimation with Constraints.*

Jun 2: **Marcel Meerstetter** (ETH), *Modelling and Control of a Spherical Pendulum.*

Jun 5: **Jacob Roll** (LiTH) *Local Modelling Using Direct Weight Optimization.*

Jun 6: **Anton Shiriaev** (University of Southern Denmark), *Stabilization of Nonlinear Systems via the Circle criterion.*

Jun 11: **Fabio Celani** (Washington University), *Omega-limit sets of nonlinear systems with high-gain feedbacks.*

Jun 12: **Brad Schofield** (LTH), *Subspace Identification for Adaptive Control.* MSc-thesis presentation.

Jun 12: **Gerard Duffin** (Imperial College), *Kinematic Analysis of Rapid Eye Movements for Vestibular Disorders.* MSc-thesis presentation.

Jun 13: **Suvaudra Ghosh** (Imperial College), *Experimental Analysis into the Use and Effects of Changing Visual Stimulus in Posturography.* MSc-thesis presentation.

Jun 24: **Anton Shiriaev** (University of Southern Denmark), *How to generate and sustain periodic motion in underactuated nonlinear systems: new ideas and principles.*

Jun 26: **Erik Casagrande** (University of Pavia), *Dynamic Vision: Shape from Motion.* MSc-thesis presentation.

Jun 27: **Johan Bengtsson** (AC), *Closed loop control of a HCCI engine.*

Aug 18: **Carlos Canudas-de-Wit** (Laboratoire d'Automatique de Grenoble), *Control of Walking Robots.*

Aug 28: **Oskar Nilsson** (LTH), *Physics based wave generation for the shallow water equations.* MSc-thesis presentation.

Aug 28: **Max Lindholm** (LTH), *Side wind compensation using active suspension.* MSc-thesis presentation.

Aug 28: **Ather Gattami** (LTH), *Analysis of Interconnected Systems.* MSc-thesis presentation.

Aug 29: **Pontus Nordfeldt** (LTH), *Regulator Design for a Flexible Servo.* MSc-thesis presentation.

Sep 5: **Vishwesh Kulkarni** (MIT), *Active Queue Management for TCP-Governed Wireless Networks.*

Sep 9: **Niclas Johansson, Tobias Folkesson** (LTH), *Speed Control of a Monochromatic Lens.* MSc-thesis presentation.

Sep 10:**Roland Pfeiffer** (LTH), *Combustion control of the HCCI process - System identification and development of an LQG regulator for the ignition phasing.* MSc-thesis presentation.

Sep 11: **Mikael Nordgren, Roger Nilsson** (LTH), *Vision-based control of the over-head crane.* MSc-thesis presentation.

Sep 12: **Tariq Samad** (Honeywell Laboratories), *From Automation to Autonomy: Implications for Software-Enabled Control.*

Sep 19: **Per-Olof Gutman** (Technion), *On the botanic model of plant growth with an intermediate vegetative-reproductive stage.*

Sep 26: **Lui Sha** (Univerity of Illinois Urbana-Champaign), *Queueing Model Based Performance Control.*

Sep 30: **Anton Shiriaev** (Umeå University), *Generating Exponentially Stable Oscillations in Nonlinear Systems with Application to Walking Mechanisms.*

Oct 14: **Ola Slätteke** (AC), *Steam and condensate system control in paper making.* Lic Tech dissertation seminar.

Oct 14: **Alf Isaksson** (ABB), *Software and applications of Grey-Box identification.*

Oct 21: **David Hill** (City University of Hong Kong), *Towards Complex System Control.*

Oct 22: **Joaquin Collado** (Cinvestav, Mexico), *Strictly Positive Real Problem with Observers.*

Nov 3: **Claus Thybo** (Danfoss), *Presentation of Danfoss.*

Nov 3: **Alessandro Bindi** (LTH, Univ Firenze), *Iterative Feedback Tuning with Application to Robotics.* MSc-thesis presentation.

Nov 13: **Ola Härkegård** (LiTH), *Backstepping and Control Allocation with Applications to Flight Control.*

Nov 20: **Christian Trobro, Mathias Magnusson** (LTH), *Förbättring av hjulhastighetssensorer genom översampling och signalbehandling.* MSc-thesis presentation.

Nov 21: **Jacob Svendenius** (AC), *Tire Models for Use in Braking Applications.* Lic Tech dissertation seminar.

Nov 21: **Rolf Johansson** (AC), *Travel Report from Tsinghua University, Beijing.*

Dec 3: **Mikael Lindberg** (LTH), *Optimazing yacht routing using dynamic programming.* MSc-thesis presentation.

Dec 12: **Dan Henriksson** (AC), *Flexible Scheduling Methods and Tools for Real-Time Control Systems.* Lic Tech dissertation seminar.

Dec 15: **Johan Åkesson** (AC), *Operator Interaction and Optimization in Control Systems.* Lic Tech dissertation seminar.