Activity Report: Automatic Control 2000

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Activity Report

Automatic Control

2000

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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, 2000.

The budget for 2000 was 24 MSEK. The proportion coming from the University was 45%.

Three PhD theses were defended this year, by Hélène Panagopoulos, Anders Wallén, and Erik Möllerstedt. This brings the total number of PhDs graduating from our department to 60. A Lic Tech thesis was completed by Anton Cervin. 2 new PhD students have been admitted during the year: Henrik Sandberg and Dan Henriksson. 4 persons with doctor's degree left the department: Mats Åkesson started to work for Biotecnol SA in Portugal, Charlotta Johnsson for ORSI Automazione SpA, Italy, Héléne Panagopoulos for Metsä-Serla Corporation in Örnsköldsvik, Sweden, and Anders Wallén for Ericsson Mobile Communications in Lund, Sweden.

In the civilingenjör (master) program we have 9 courses. The total number of students that finished the courses were 721, and 33 students completed their master theses. The total teaching effort corresponds to 112 full-year equivalents.

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

Some members of the department have received honors and awards, see Chapter 9. For instance, the IEEE Board of Directors elected Anders Rantzer to IEEE Fellow.

Karl-Erik Årzén was promoted to professor in automatic control at the department, June 1, 2000. The department now has seven professors and one professor emeritus.

During the year the department has participated in the formation of LUCAS - Center for Applied Software Research at Lund Institute of Technology. The center is a collaboration between the software related activities at three departments: Automatic Control, Computer Science, and Communication systems. The center is funded by NUTEK/VINNOVA, Swedish industry, and Lund University.

A workshop entitled "Hybrid Control and Automotive Applications" was organized in Lund, May 5-6, 2000 with support from EU and TFR. Sixteen leading European scientists gave invited presentations and several companies contributed as well.

Our retrospect this year, Chapter 7, describes our research in robotics since the mid 1980s.

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

	95-96	97	98	99	00	Sum
Books	1	2	1	2	0	6
Papers	30	15	24	24	18	109
Conference papers	71	45	37	45	37	235
PhD theses	3	1	2	7	3	16
Licentiate theses	2	3	6	1	1	13
Master theses	40	18	20	25	24	126
Internal reports	18	11	11	8	5	53

Acknowledgments

We want to thank our sponsors, Swedish National Board for Industrial and Technical Development (NUTEK), Swedish Research Council for Engineering Sciences (TFR), Swedish Natural Science Research Council (NFR), Swedish Medical Research Council (MFR), Elforsk, The European Council, Foundation for Strategic Research (SSF), The Swedish Foundation for International Cooperation in Research and Higher Education (STINT), ABB Automation Products AB, ABB Robotics AB, Active Biotech, Lund Research Center AB, Ericsson Mobile Communications AB, LM Ericsson Foundation, Nordkvist, Pharmacia & Upjohn, SBL Vaccin AB, Sydkraft AB, Tetra Pak Research & Development AB, The Royal Physiographic Society, and Volvo Techical Development AB, for their support to our projects.

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, 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.

The department has also an unofficial home page:

```
http://www.regler.nu
```

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
```

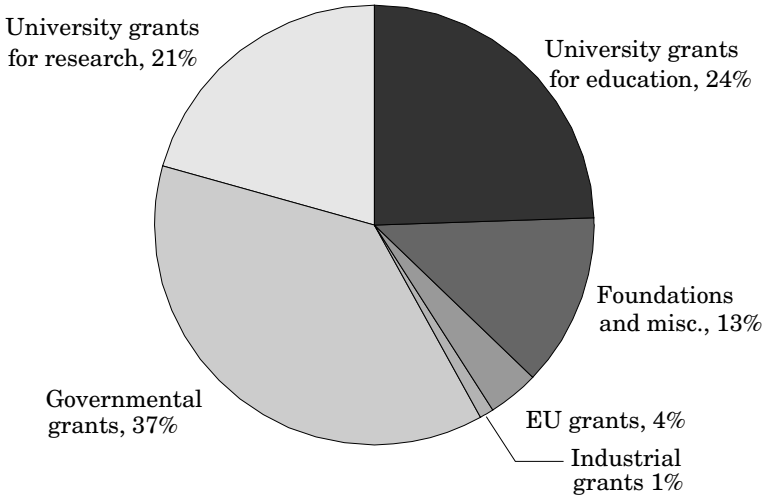
Our web page `http://www.control.lth.se/people/telemail.html` contains a complete list of email addresses. The department also has a generic email address:

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

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

3. Economy and Facilities

The turnover for 2000 was 24 MSEK. The income comes from Lund University (45%) 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 2000 we had the following contracts:

- TFR – Control of Industrial Processes (block grant)
- NUTEK – Modeling and Simulation of Complex Systems

- NUTEK – Lund Research Programme in Autonomous Robotics
- NUTEK – Data Integration and Force Control for Robots
- NUTEK – Automatic Control and Driver Model
- NUTEK – Motion Control
- NUTEK – Process Control for Cultivation of Micro Organisms
- NUTEK – Application Specific Real-time Systems: Programming of Control Systems
- NUTEK – Distributed Control of Safety Critical Systems
- NUTEK – Basic Control Functions for the Process Industry
- NUTEK – Lund Center for Applied Software Research (LUCAS)
- STINT – Funding for research collaboration with Caltech
- SBL Vaccin AB – Evaluation of a new method for supply of carbon source
- SSF – Center for Chemical Process Design and Control (CPDC)
- SSF – Computational Analysis of Dynamical Models
- SSF ARTES – Integrated Control and Scheduling
- ELFORSK – Modeling of Electric Power Networks
- Sydkraft – Modeling and Control of Energy Processes
- Pharmacia&Upjohn – Control of Genetically engineered *E. coli*.
- EU ESPRIT LTR – Fuzzy Algorithms for MIMO Control (FAMIMO)
- EU ESPRIT LTR – Heterogeneous Hybrid Control (H2C)
- EU HPRN-CT - Nonlinear and adaptive control (NACO2)

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

Facilities

The main facilities are laboratories and computer systems. Our main computing resource is a network of Unix workstations. All members of the department have on their desks workstations connected to this network. For all academic staff the machines are SparcStation Ultra1 or better. There is also a powerful central computer for heavy computations.

Teaching Laboratory

The teaching laboratories are based on desktop processes and personal computers. These laboratories are used in all our courses. The introductory courses give a heavy load on the teaching laboratories because of the large number of students. There are more than 700 students, and on the average they spend about 20 hours each in the lab.

The use of Linux with UTIME in the lab has been further consolidated. It gives us a very stable environment with good performance for soft Real-Time experiments. The Linux configuration is: Red Hat 6.x, UTIME kernel timer resolution patch, COMEDI control and measurement device interface (`http://hegel.ittc.ukans.edu/projects/utime` and `http://stm.lbl.gov/comedi`).

Robotics Laboratory

The Robotics Laboratory, containing two industrial robot manipulators (Irb-6 and Irb-2000) together with the Open Robot Control architecture

developed at the Dept of Automatic Control (see "Looking back on Robotics Research"), serves as a good common experimental platform for research activities from many different departments and research groups.

Matlab/Simulink interfaces for down-loading 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, also allow a lot of student projects and master thesis projects to use the facilities in the RobotLab.

During 2000, a new robot system (Irb2400/S4C+) from ABB Robotics, Sweden, was installed. Modification of the controller structure is done in close corporation with ABB Robotics. The new robot was placed in the laboratory belonging to the Division of Robotics/Dept. Mechanical Engineering.

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), and Chemical Engineering (K). Our courses are listed in Table 4.1.

During 2000, 721 students passed our courses and 32 students completed their master-thesis projects. The number of registered students corresponded to 112 full-year equivalents during the year.

Topics for the master theses were in the following areas: Adaptive control (2), Control of nonlinear and uncertain systems (4), Modeling and simulation (2), Signal processing (3), Real-time systems (2), Robotics (3), Automotive applications (2), Process control and power system and tuning (6). A list of the master theses is given in Chapter 13.

Information on WWW

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

Table 4.1 Courses and the number of students who passed.

Reglerteknik AK–FEDI *FRT010* (Automatic Control, basic course)	411
Reglerteknik AK–M *FRT061* (Automatic Control, basic course)	116
Processreglering (K) *FRT080* (Automatic Process Control)	16
Digital Reglering (FED) *FRT020* (Computer-Controlled Systems)	46
Realtidssystem (FED) *FRT031* (Real-Time Systems)	62
Systemidentifiering (FED) *FRT041* (System Identification)	19
Adaptiv reglering (FED) *FRT050* (Adaptive Control)	22
Olinjär reglering och Servosystem (M) *FRT075* (Nonlinear Control and Servo Systems)	21
Projekt i reglerteknik *FRT090* (Project in Automatic Control)	4
Internationell projektkurs i reglerteknik *FRT100* (International Project Course in Automatic Control)	4
Examensarbete 20 poäng *FRT820* (Master-thesis project, 5 months)	24

We have also made information sheets about the engineering courses and the doctorate program, and they were received very well. You find the education links at `http://www.control.lth.se/education/`.

Doctorate Program

Three PhD theses were defended by Anders Wallén, Hélène Panagopoulos, and Erik Möllerstedt. This brings the total number of PhDs graduating from our department to 60. A Lic Tech thesis was completed by Anton Cervin. Abstracts of the theses are given in Chapter 8.

We have admitted two new PhD students during the year: Henrik Sandberg and Dan Henriksson.

The following PhD courses were given:

- Linear Systems I (A. Rantzer) 5 points
- 25 seminal papers (B. Wittenmark) 4 points
- Hybrid systems (A. Rantzer) 3 points
- Physical modeling of dynamic systems (K. J. Åström) 4 points
- Model predictive control (J. Rawlins) 3 point
- Basics of robust control (A. Ghulchak) 5 points
- Synthesis (B. Bernhardsson) 5 points
- Languages for automation (K-E Årzén) 4 points

5. Research

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

The major research areas are:

- Nonlinear and Uncertain Systems
- Modeling and Simulation
- Process Control
- Robotics
- Real-Time Control
- Applications

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: Anders Rantzer, Bo Bernhardsson, and Andrey Ghulchak

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.

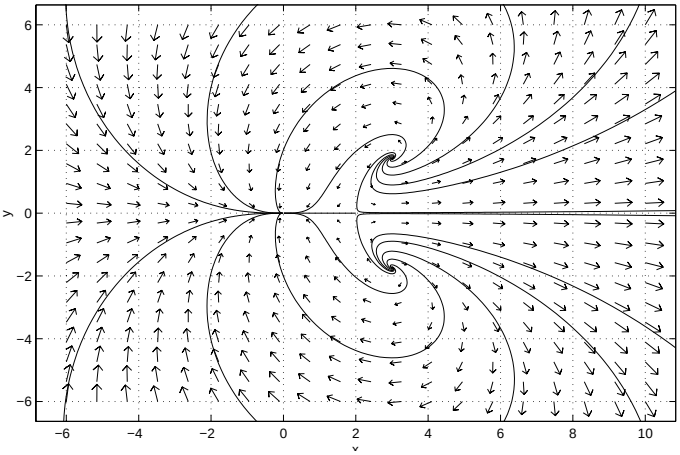


Figure 5.1 Phase plane plot for the system $(\dot{x}, \dot{y}) = (-2x + x^2 - y^2, -6y + 2xy)$

This year, 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. One is the difficulty to get global results for systems with several equilibria. Moreover, important difficulties in control synthesis can be traced back to the fact that the set of control Lyapunov functions for a given system is generally non-convex and sometimes disconnected. Our main 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. This makes it easier to get global results. For example, the criterion can be used to verify in a few lines of hand calculations that almost all trajectories of the system $(\dot{x}, \dot{y}) = (-2x + x^2 - y^2, -6y + 2xy)$ converge to zero. See Figure 5.1. Furthermore, the new criterion enjoys a powerful convexity property in the context of control synthesis.

For several years, we have been developing the analysis framework based on integral quadratic constraints. This work is done in cooper-

ation with Prof. A. Megretski at MIT. The activity has resulted in a sequence of joint publications and a Matlab tool-box named IQCbeta to support the analysis of interconnected systems.

Andrey Ghulchak works as guest researcher and together with Anders Rantzer he studies optimization with frequency domain constraints. This problem area has a wide variety of applications in control. An important result is that we can use convex optimization tools to prove that certain sets of controller specifications are not possible to satisfy by any controller.

Hybrid Control

Researchers: Karl Johan Åström, Bo Bernhardsson, Sven Hedlund, 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 modelled as discrete events. Examples are mechanical systems with backlash, dead zones, and static friction, or electrical systems with switches.

The department is one of four partners in the ESPRIT-project "Heterogeneous Hybrid Control". Within this project, a computational approach to hybrid systems has been developed. The work is directed towards stability, performance, and optimal control for hybrid systems. Piecewise quadratic Lyapunov functions and cost functions are computed by convex optimization. The method is a generalization of earlier work on quadratic stability and gives big flexibility for analysis of hybrid systems.

Two demonstrator problems are provided by DaimlerChrysler. The main one is concerned with control of ABS brakes, where a hybrid control structure is motivated by rapidly changing road conditions and actuator constraints.

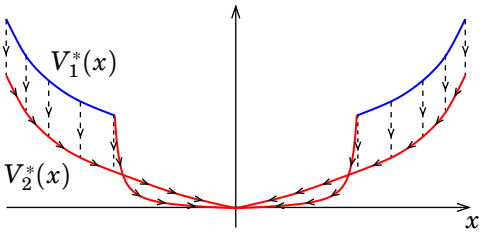


Figure 5.2 Optimal cost functions for a simple hybrid control problem. A vehicle should be brought to desired position and velocity using gear shifts (discrete) and throttle adjustment (continuous). A unit cost is assigned to each gear shift.

Analysis of Electric Power Quality in Distribution Networks and Loads

Researchers: Bo Bernhardsson, Erik Möllerstedt, Henrik Sandberg, and Anders Rantzer

The introduction of power electronics has dramatically changed the field of power systems during the last decades. Power electronic devices increase the flexibility and make more optimal utilization of the grid and improved load performance possible. New concepts and solutions have emerged, like high voltage dc (HVDC) transmission and distributed power generation (DPG). The deregulation of the electricity market has further helped to make these new concepts economically viable. To allow for a more optimized operation of the system, accurate methods for analysis and control design are essential. However, the fast switching nature of power electronics leads to systems that are very hard to analyze. Traditional stability analysis of power systems is based on linear time invariant models with slow dynamics, and assumes all signals to be sinusoidal. This is no longer sufficient in order to guarantee stable operation and to fully utilize the capacity of the power electronic devices.

Only relatively small deviations from the nominal voltage are allowed, so our approach is to linearize the system around the nominal operating trajectory. Power systems are driven by a voltage of fixed

frequency and amplitude (generally 50 or 60 Hz), leading to periodic nominal trajectories, despite the switching dynamics of the power electronics. Linearization around periodic trajectories leads to linear time periodic (LTP) models.

Actively controlled power electronic devices like power converters, are very powerful actuators. Power flows can be changed in a fraction of a cycle. Since the grid itself is not low pass, the total system cannot be assumed to have slow dynamics. Furthermore, because of the switching dynamics, there is coupling between frequencies. Consequently, to fully utilize the possibilities brought by the power electronics, and to avoid too conservative solutions, harmonics and frequency coupling must be taken into account. This coupling is captured by the linear time periodic models.

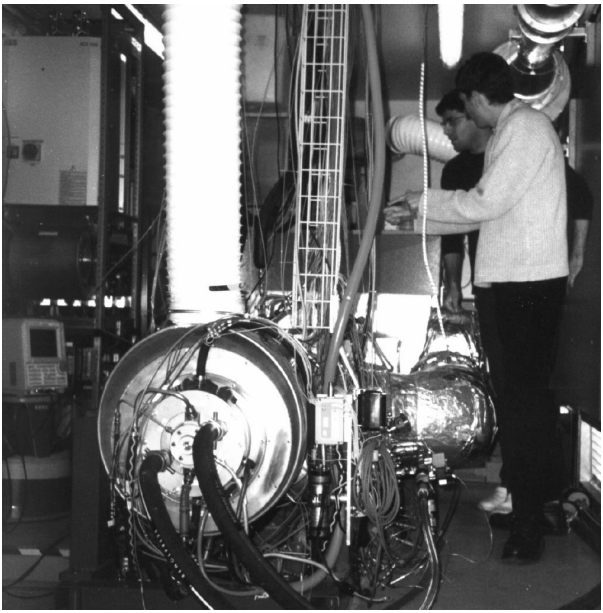


Figure 5.3 A small 100 kW micro-turbine used for distributed power generation. It is connected to the grid via power electronic converters.

Current standards for assuring stability in power systems are based on old fashioned assumptions and have poor theoretical justification in modern power technology. They are often very conservative and lead to loss of efficiency and money. However, modeling power systems as LTP systems, modern analysis and design methods from robust control become applicable. There are many results from control theory that can be used to improve network operation. In particular, LQG and H_∞ control for LTP systems can be used to improve stability and robustness.

Modeling and Simulation

Modeling and Simulation of Complex Systems

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

The main aim of this project is to develop methods and computer tools which support development and use of mathematical models. The basic idea is to support reuse, so that a model component can be used as a part in different applications to solve a variety of problems. Good model libraries should allow a user to make the desired model simply by combining components. Computer tools should automate the analysis and manipulation, which has to be done manually today to get the problem on a form that is efficient for numerical simulation.

The project started as a computer tool development project and later shifted towards model library development, model language standardization, and model reduction methods. The department is an active member in the design of the modeling language Modelica™, which started at a meeting in Lund in 1996. With support from ESPRIT, "Simulation in Europe", the design of Modelica Version 1.0 was finished in September 1997. Now, Version 1.4 has been released and the commercial simulation tool Dymola supports Modelica since more than a year. Several other companies and universities have announced Modelica based tools soon to be released. The language definition and other information on the Modelica effort are available on the web site `http://www.Modelica.org`

A very important part of the Modelica effort is development of model libraries. The department has for some years been developing models for energy processes. This has resulted in a Modelica base library for thermo-hydraulic systems, ThermoFlow. The base library contains models for lumped or discretized control volumes, based on the physical balance equations of mass, energy and momentum. The ThermoFlow library is designed to be flexible, using Modelica class parameters to exchange medium property descriptions and flow machine characteristics. In the library, particular attention has been given to efficiency for dynamic simulation of medium property functions, since standard medium models are built for static calculations. The work on the ThermoFlow library was presented at the first Modelica workshop in October, organized by the department. The workshop was a success with over 90 participants, of which more than half were industrial representatives.

Within the project there is also an effort to combine the experiences of object-oriented modeling with basic concepts of robust control. For example, an object oriented model of the Nordel power grid was recently used to generate data for a Matlab analysis of worst case parameter combinations for power grid stability. Currently, efforts are made to use model reduction concepts for periodic systems on a model for flow oscillations in two-phase flow through a heated pipe.

System Identification

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

An identification algorithm that effectively fits continuous-time transfer functions and finite-bandwidth noise models to data has been published. Analysis of this class of algorithms proves convergence properties similar to that of maximum-likelihood identification of discrete-time ARMAX models. A substantial improvement of the identification accuracy of continuous-time zeros appears to be an important and attractive property of the new algorithm.

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

One research direction that is currently pursued is system identification methodology suitable for multi-input multi-output systems for which matrix fraction descriptions are not unique. A promising approach to system identification appears to be the continued-fraction approximation and we have published a number of new matrix fraction descriptions and theoretical results that resolve such problems of uniqueness. However, several theoretical problems remain to be solved with regard to algorithm efficiency, statistical properties and validation aspects.

Biomedical Modeling and Control

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

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

Process control

Center for Chemical Process Design and Control (CPDC)

Researchers: Karl-Erik Årzén, Tore Hägglund, Ari Ingimundarsson, Rasmus Olsson, Hélène Panagopoulos, Henrik Sandberg, Anders Wallén, and Björn Wittenmark

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

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

The projects 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 system design
  - PID control
  - Autonomous control
- Control and diagnosis in batch processes

Interaction measures in process control

Researchers: Björn Wittenmark in cooperation with Mario Salgado, Universidad Técnica Federico Santa Maria, Valparaiso

In the process industry there is a great need for determining suitable structures of controllers. In many cases diagonal or block-diagonal controller structures are desired. In the literature there are many different methods for pairing of inputs and outputs. In this work a new form of interaction measure for multiple-input-multiple-output systems is introduced. The interaction measure, Hankel Interaction Index array, is an extension of the relative gain array (RGA). The advantage with the new measure is that it takes the frequency behavior of the system into account when deciding the input-output pairing of a system. The derivation is based on a gramian based interaction measure, but modifications are done which better reflect the controllability and observability of the subsystems in the process.

Modeling and Control of the Drying Sections of a Paper Machine

Researchers: Alessandro Pontremoli, on leave from University of Rome, and Björn Wittenmark, in cooperation with Krister Forsman, ABB Automation Systems

The main purpose of this project has been to model a steam heated cylinder, which was taken as part of a drying section, moreover the design and structure of an existing process has been taken into consideration.

To develop this work the Modelica software has been used. Particular attention has been paid to reproduce the two time constants behavior of the dynamics in the pressure control loop. This behavior has been observed in existing industrial processes. Other dynamics in the system include; fluid dynamics concerning momentum flow, convictive heat flow and pressure, heat dynamics concerning heat flow and temperature inside the cylinder shell has been included.

The basic control volume, flow, and medium models are all inherited from the “ThermoFlow” library, which is still under development at the department.

The control is done via a PI controller and the lambda tuning method is used to tune it. The performance of the whole system was improved. The main contribution of his thesis is to link previous works, which concern paper web modeling and others that concern modeling of thermo-hydraulic systems.

Rejection of narrow-band disturbances subject to uncertain time-delays

Researchers: Björn Wittenmark in cooperation with Sergio Savaresi, Politecnico di Milano

The problem of designing feedback controllers for the rejection of narrow-band disturbances is considered in this project. The design technique proposed herein is based upon the over-parameterization of a nominal minimum-variance controller, which is designed by means of an ARMA model of a sinusoid in noise. The extra degrees of freedom so introduced are used to improve the robustness of the nominal controller, when the time delay of the plant is subject to uncertainties, by minimizing a minimum-variance performance index along an one-dimensional line.

PID Control

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

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

During the last year, Hélène Panagopoulos has defended her PhD thesis *PID Control – Design, Extension, Application*, presenting efficient numerical methods for designing PID controllers based on non-convex optimization, as well as extensions of the PID controller to suit oscillatory systems. Applications in paper mills are also provided.

Several smaller projects with industrial collaboration concerning implementation aspects of PID control have been initiated during the year.

Autonomous Control

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

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

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

During the last year, Anders Wallén has defended his PhD thesis *Tools for Autonomous Process Control* within the project.

Dead-time compensation in process control

Researchers: Ari Ingimundarson and Tore Hägglund

Processes with long dead-time frequently cause problems within the process industry. In practise these processes are controlled by PI-controllers. Dead-time compensators with superior performance have been around for a long time but the use of these introduces new problems related to the tuning and maintenance.

This project has been focusing on the commissioning and tuning of dead-time compensators. Methods of identification of simple process models have been developed. Attention has been given to the robustness aspects of dead-time compensation. Special focus has been on the

robustness towards error in the dead time. When dead time is uncertain but lies on an interval around a nominal dead time, it has been shown how stability can be guaranteed for a specific dead-time compensator. Dead-time compensators for integrating processes have been considered as well. Finally, the performance of dead-time compensators compared with the PI-controller has been investigated to determine when their use is appropriate.

The project is sponsored by the Swedish Foundation for Strategic Research (SSF) within the CPDC project and by NUTEK's research program on Complex Systems.

Basic process control functions

Researchers: Tore Hägglund, Ari Ingimundarson, and Hélène Panagopoulos

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

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

The second project treats ratio control. Traditional Ratio stations fail to keep the ratio during transients. A new ratio control structure, the Blend Station, that manages to keep the ratio even during transients has been developed. Results from industrial field test are shown in Figure 5.4. The Blend Station is patented.

The third project treats control of oscillatory systems. A filter, composed of an all-pass filter and a band-pass filter, is designed to perform active control of the undamped modes. The parameters of the filter are obtained from a few characteristics of the frequency response.

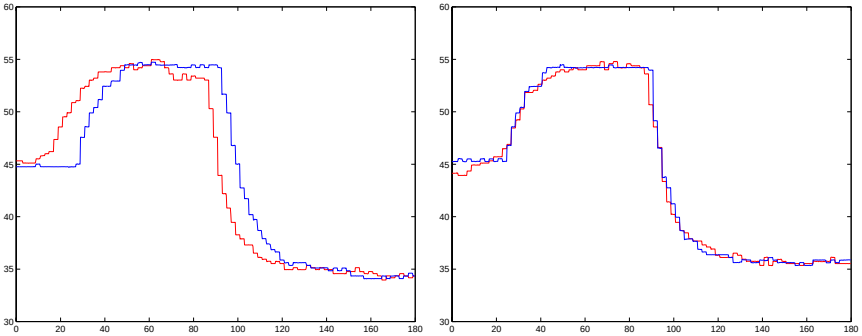


Figure 5.4 Ratio control of a bleaching process in a paper mill using the traditional Ratio station (left) and the Blend station (right).

Control Loop Monitoring

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

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

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

During 2000, the work has focused on feedforward control, with a patent pending. Currently, the ideas are being implemented in real-time Java for use on both virtual and laboratory processes.

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 will be put on integration of the monitoring and supervision tasks with recipe-based production. Two main issues will be investigated. The first issue studies the interaction between recipe execution and supervision. A model-based approach will be 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 Grafchart, a graphical sequential programming language that and its applications to batch recipe management and resource allocation. The focus of this part of the project is to extend Grafchart by adding different features that support exception handling in batch production.

During 2000, an internal model based approach to supervision of recipe execution has been developed and implemented.

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 Pharmacia & Upjohn, Process R&D. Information of how to change the substrate feed rate is obtained from standard dissolved oxygen measurements by introducing controlled process perturbations. Tuning rules are derived for the control strategy that assume a minimum of process specific information, and the system is analysed for stability.

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

The strategy is now implemented at the Departments of Biotechnology and Chemical Engineering, Lund University, at Active Biotech, in Lund and at SBL 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.

The work is funded by NUTEK, “Bioprocesser i industrin”, and by Pharmacia AB and Active Biotech.

Robotics

Robotics Research and Nonlinear Systems Research

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

The laboratory for robotics and real-time systems is centered around an ABB Irb-6 robot and an ABB Irb-2000 robot. Hardware interfaces have been developed to create an open system suitable for control experiments. The computer hardware is VME-based with both micro processors and signal processors integrated into an embedded system for hard real-time control. The system is connected to a network with Sun workstations, which are used for program development and control design. A purpose of the current project is to show how to organize open robot control systems and to verify these ideas by means of experiments. One goal is to permit efficient specification and generation of fast robot motions along a geometric path which requires coordinated adjustment of the individual joint motions. Another aspect of robot motion control is how to to integrate simultaneous control of force and position according to ideas of impedance control in which stability is an important theoretical issue. A major topic in this project is to integrate aspects of control, sensor fusion and application demands.

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

During this year, a new robot (ABB Irb 2400/16 S4C+) was made

available to the laboratory (courtesy of ABB Robotics).

Real-Time Control

Center for Applied Software Research (LUCAS)
Researchers: Karl-Erik Årzén, Bo Bernhardsson, Rolf Johansson, Anders Robertsson, Johan Eker, Anton Cervin, Bo Lincoln, Magnus Gäfvert, 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. Currently, Ericsson Mobile Communications AB and ABB Automation Products AB are gold members. Negotiations are ongoing with a large number of companies.

Distributed Control of Safety Critical Mechanical Systems

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

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

As a means to combine methods and theory from automatic control, computer engineering, and mechatronics in the field of distributed safety-critical control systems, a case-study has been initiated in co-operation with Volvo Technological Development (VTD). The subject of the study is an electrical braking system with integrated anti-lock and yaw-control functionality for heavy duty tractor-trailer combinations. This system is a distributed safety-critical control system by nature. It is believed that the design and understanding of this system can be greatly enhanced by applying and combining methods within the areas of design of dependable computer systems and control theory. The study is expected to result in new general insights in design and development methods for dependable distributed control systems.

The case study was started up in 1999 with a literature study and a study of present electrical braking systems at Volvo as a first step. A study of a present system was presented in a report. During 2000 a fairly detailed simulation model of the vehicle has been constructed and presented in a report. This model will be used to investigate properties of different system designs. Another report presents a proposal on a system architecture based on dependability analysis.

Three graduate students are active in the case study: Magnus Gäfvert (Department of Automatic Control), Vilgot Claesson (Department of Computer Engineering, Chalmers), and Martin Sanfridsson (Mechatronics Lab, KTH). The work during 2000 was concentrated to 9 weeks when the graduate students worked together at VTD. This enabled a closer cooperation, with the possibility to develop cross-disciplinary ideas and thoughts.

Integrated Control and Scheduling

Researchers: Anton Cervin, Johan Eker, Anders Blomdell, and Karl-Erik Årzén, in cooperation with Sigma Exallon AB, DDA Consulting, and Professor Lui Sha at the Department of Computer Science, University of Illinois Urbana-Champaign

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 "Interactive Execution Time Analysis" performed by the Department of Computer Science, Lund University. Additional project partners are the two real-time software consulting companies Sigma Exallon AB and DDA Consulting, and Professor Lui Sha at the Department of Computer Science, University of Illinois Urbana-Champaign. The project finances two ARTES PhD students, Anton Cervin at Automatic Control, and Patrik Persson at Computer Science.

During 2000, the work on feedback scheduling has continued. A scheduling architecture for real-time control tasks has been developed. The scheduler uses feedback from execution time measurements and feedforward from work load changes to adjust the sampling periods of the control tasks so that the combined control cost of all the controllers is minimized. An LQG-control formulation is used.

Other issues that have been studied are the performance of EDF scheduling in overload conditions and the effects of deadline misses on control performance. The work on a MATLAB/SIMULINK based simulator for integrated simulation of controlled processes, control algorithms, and the timing effects caused by a real-time operating system has continued.

During this year Anton Cervin has presented his Licentiate Thesis and an invited session has been arranged at CDC 2000.

Application Specific Real Time Systems: Programming of Control Systems

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

The topic of the project is development of flexible programming languages and environments for implementation of real-time control systems. PÅLSJÖ, a software environment for rapid development of embedded real-time control systems and has been developed within the project. Friend, the next generation of Pålsjö/PAL, is a small block based language designed for implementing flexible embedded control systems using contracts and negotiation. It is designed to support for the implementation of flexible and adaptive embedded control systems. Requirements on a controller are specified using contracts. The use of contracts simplifies the design and implementation of embedded systems that can adapt to altered operating conditions. The contracts allow the system to negotiate about resources, and redistribute them when necessary.

An experimental setup is currently being designed around a Koala mobile robot from the Swiss company K-Team. A Java virtual machine designed for real-time use, the IVM, developed by Anders Ive at Department of Computer Science is currently being adapted to run on the Koala robot. The idea is to let the robot communicate with a host system or other mobile units through Bluetooth. The IVM is also being used as the platform for the development of a deadline-based real-time kernel.

Networked Control Systems

Researchers: Bo Lincoln, Johan Eker, Anders Blomdell, Anton Cervin, Bo Bernhardsson, Björn Wittenmark, and Karl-Erik Årzén

As computer networks evolve and get cheaper and more powerful, they tend to be used for purposes for which they were not designed – for example transmitting automatic control data. This project is focused on using wireless or fixed networks in the control loop, and dealing with two major problems:

- How to cope with the inherent problems of networks, such as delays and unreliability.

- How to improve the control performance of networks, by for example doing automatic data scheduling.

The aim of the projects is to make it easy (by tools or methods) to design control systems which use networks for data transfer. So far, we have developed methods to solve small optimal switching (data scheduling) problems and we have developed optimal control design for networks with long delays. A particular emphasis of our work has been Bluetooth. A Java-based Bluetooth stack has been developed. Bluetooth has also been evaluated in different laboratory setups.

Applications

Automotive Systems: Adaptive Cruise Control and Driver Models

Researchers: Rolf Johansson and Johan Bengtsson, in cooperation with A. Sjögren, Volvo Technical Development, Inc., Gothenburg

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

Control of Gasoline Direct Injection (GDI) Engines (FAMIMO)

Researchers: Magnus Gäfvert and Karl-Erik Årzén

FAMIMO (Fuzzy Algorithms for MIMO Control Systems) is a 3.5 year Esprit reactive long term research (LTR) project that started 961201 and finished 000601. The project has four academic partners and one industrial partner, Siemens Automotive in Toulouse. The project is organized along two benchmark studies: control of a gasoline direct injection (GDI) engine and control of a wastewater fermentation process.

During 2000 the work in the project has focused on control of the GDI engine. A GDI engine can operate in two main modes: homogeneous mode and stratified mode. The homogeneous mode corresponds to the combustion principle of a normal PFI (Port Fuel Injected) gasoline engine where fuel is injected during the air intake stroke. In the stratified mode, fuel is injected during the compression stroke which makes it possible to employ high air/fuel ratios, leading to lower fuel consumption. The GDI engine is more complex than an ordinary PFI engine and therefore requires a more advanced control system. Special care must be taken to the combustion mode switches.

The goal is to design an engine management system (controller) that follows the reference signals from the driving cycle while minimizing fuel consumption and emissions, and maintaining the driving comfort. During 1998-99 a linear control design were developed. During this year the design has been further elaborated. An extremum control approach is used to obtain low fuel consumption in stratified mode. An idle speed controller has been developed. The control design has been evaluated on the European driving cycle scenario with very good results.

Motion Control of Open Packages Containing Fluid

Researchers: Mattias Grundelius and Bo Bernhardsson

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

The focus in the project has been movement of open packages containing liquid. All packages in the machine follow the same acceleration profile. Between the filling station and the sealing station the package is moved one or several times. The aim is to find the acceleration profile that minimize the movement time with a maximum allowed slosh.

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

The model used when calculating the acceleration profiles is very simple and therefore the calculated acceleration profiles do not perform as expected if the slosh is large. To overcome this two Iterative Learning Control (ILC) algorithms have been developed which successfully increases the performance.

The project is funded by NUTEK and is performed in collaboration with Tetra Pak Research & Development AB in Lund, who has supplied the experimental equipment and valuable process knowledge.

Cardiologic Analysis and Modeling

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

This project is directed towards chronic atrial fibrillation (CAF), one of the most common cardiac arrhythmias in man and associated with increased morbidity and mortality. Previous studies in animals have shown that experimental atrial fibrillation is based on different types of intra-atrial electrical re-entry. By exploring the activation of the right atrial free wall during open-heart surgery in patients with CAF and an underlying heart disease, we confirmed the presence of re-entry mechanisms. In addition, areas with organised activation were identified. The nature of the organised activation suggested re-entry in an anatomical structure, like the right annular bundle surrounding the tricuspid valve. In patients without signs of organised activation, multiple activation waves continuously re-enter due to functional

properties of the atrial myocardium. An interesting result was that we failed to demonstrate that anisotropy in conduction velocity be a general property of the epicardial right atrial free wall of the intact human heart in patients with stable sinus rhythm as well as in patients with CAF.

6. External Contacts

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

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

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

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

Industrial Contacts

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

ABB Automation Systems,
ABB Automation Products,
ABB Corporate Research,
ABB Power Systems,
ABB Robotic Products,
ABB SuHAB,
Active Biotech Research AB,
Akzo Nobel-Eka Chemicals AB,
DaimlerChrysler,
Danfoss AS,
DDA Consulting,
Dynasim AB,
Elforsk,
Ericsson Mobile Communications,
Gensym Corp.,
Pharmacia & Upjohn,
Sigma Exallon AB,
Siemens Automotive,
SINTEF,
Sydkraft,
TAC,
Telelogic,
Tetra Pak Research & Development,
Volvo Technical Development.

We have had smaller projects with

Astra Draco,
Astra Hässle,
Alfa Laval Thermal,
Cellavision,
Comsol,
Haldex Traction,
MEFOS,
Modo Paper Husum,
Novotek,
Pulp and Paper Industries Engineering Co. (STFI),
SIK – Institutet för livsmedel och bioteknik AB,
Stora Hylte AB
Vattenfall.

and meetings and discussions with many other companies.

European Collaboration

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

We are members of the Research Training Network *Nonlinear and Adaptive Control (NACO2)* coordinated by Imperial College, London.

We have been a member of the ESPRIT project FAMIMO, *Fuzzy Algorithms for MIMO Control Systems*, that ended in June 2000. The project has four academic partners and one industrial partner, Siemens Automotive in Toulouse (`http://iridia.ulb.ac.be/~famimo/`).

7. Looking back on Robotics Research

As robots provide tangible demonstrators of the merits of control for audiences at all levels of scientific sophistication ranging from kindergarten to students and to faculty members, the Robotics Laboratory of Department of Automatic Control is one of the favorite meeting points for visitors and guests.

Robotics is a research area with intimate relationships with control and computer science, yet with an independent multidisciplinary character. Beside the mechanical nature of robots, robots requires all the cybernetic elements of control, communication and computation and robotics can never be reduced to a mere application of control theory. Apart from control science, successful robotics require efforts in mechanical design, motor drives or other actuators, sensor technology and software engineering. Therefore, the history of robotics at our department is closely relate to the history of the enabling technologies, including the projects and researchers that contributed to the developments. In this perspective, the progress within digital control, real-time systems, visual feedback, and control of mechanical servos, deserves some attention. The preliminaries of robotics at the Department of Automatic Control have at least a history of 30 years.

7.1 Preliminaries (1970–1984)

To the purpose of the educational laboratory, Leif Andersson made DEC servo equipment with an interface to analog computers. The DC servos permitted sensor feedback of position and velocity and were used for many years in the basic course for most students. Another important prelude to robotics was the design of the ball-and-beam process which was designed by Johan Wieslander and Karl Johan Åström with

mechanical design and construction by Rolf Braun and Hans Libelius, technician at our neighboring Dept Sold Mechanics. Much of this design work was done in the framework of Johan Wieslander's thesis work and the equipment brought early attention to problems of nonlinear control and real-time control. Early control was made by means of computer-based control using a PDP15 from Digital Equipment, Inc.

Computer-based control with all attempts to connect computers to control equipment and other peripheral devices also stimulated networking. Early efforts in network-based control was made by Rolf Syding, Ulf Borisson, Leif Andersson and colleagues in effort to control an ore crusher of LKAB – a mining company in northern Scandinavia. By connecting the ore crushing plant over the telecommunication network, a geographically long feedback loop (>3000km) was connecting to real-time control in a PDP15 computer. Rolf Braun designed an actuator interface.

During his time as graduate student, Lars Nielsen made early efforts in visual servoing, partly in cooperation with Gunnar Sparr, Dept Mathematics, Lund. During his thesis work, Lars Nielsen developed a small, but impressive in terms of its purpose, mobile robotics laboratory. After his postdoc visit to CalTech in 1986, Nielsen returned to Lund and took initiatives to continued robotics research in cooperation with Ola Dahl and Klas Nilsson who had joined Department of Automatic Control as PhD candidates. The focus now was industrial robotics, which includes most of the challenges within mobile and autonomous robotics, but also brings forward industrial relevance and performance demands. With the new focus, with the PhD students Ola Dahl and Klas Nilsson, and with a great interest from Karl Johan Åström, Lars Nielsen, Rolf Johansson and other faculty members, new experimental facilities were created.

After his dissertation on multi-variable adaptive control in 1983, Rolf Johansson started theoretical work in nonlinear control with an application perspective on mechanical systems. Another source of inspiration came from biological inspiration acquired from his experience in neuroscience research. New algorithms and analytical results for adaptive control and nonlinear optimal control were published in 1987-1990.

7.2 Early days of the Robotics Laboratory at Department of Automatic Control (1983–1992)

Initiated by Karl Johan Åström and with a great interest and support from Lars Nielsen, Rolf Johansson and others at the department, the first industrial manipulator was acquired from ASEA in 1984. At ASEA there was an increasing need for computer-based control engineering tools, which was something that was being developed at the department. When the first industrial robot, an ASEA Irb-6 (designed around 1978) equipped with the S2 control system designed during 1981-82, was acquired, it was actually made in exchange of the control design and simulation software packages (Simnon, Synpac, Modpac, and Polpac) developed and sold by the department. At ASEA, it was the manager of technical development, Hans Skoog who approved the deal proposed by Klas Nilsson. Also, the first PhD student with a clear focus on robot control started, namely Ola Dahl started in 1984. Klas Nilsson, who had been a student at Lund made his master thesis work at ABB Robotics, and started his professional career as a control engineer at ABB Robotics. Few individuals have greater credit than Klas in the creation of a Robotics Laboratory. While still at ABB Robotics, Klas was instrumental already in early use of the Irb-6. When beginning as a graduate student at the department in 1988, he started work on hardware modification to permit highly modifiable control software architectures.When beginning as a graduate student at the department in 1988 with Lars Nielsen as graduate advisor, he started work on hardware modifications to permit highly configurable control software architectures.

Important interfacing work was made in cooperation with Rolf Braun. There was an earlier interface of a pure analog type, permitting some experiments in restricted parts of the working range of the robot. Since Klas knew the inner workings of the system, it was possible to interface external computers with the safety logic of the embedded controller. Important interfacing work was made in cooperation with Rolf Braun who replaced all original electronic hardware (except for power electronics). This work on the Irb-6 started in 1990 and the Irb-2000 was modified in 1992.

During his time as a graduate student under guidance of Ioan Landau (CNRS at ENSIEG-LAG, Grenoble, France), Carlos Canudas de Wit spent the greater part of 1985 in Lund as a guest of Karl Johan Åström. He was using methods of system identification and friction modeling to develop friction compensation in servo applications. Interaction with Rolf Johansson, who at that time was developing system identification methods for continuous-time models, combined with Carlos interest in friction modeling and eventually this gave rise to the LuGre friction model.

Steve Murphy who was then graduate student at RPI under supervision of Prof. George Saridis spent the academic year 1987-88 in Lund. After his graduation from RPI, and after some time at Fanuc Robotics, Detroit, MI, Steve joined ABB Robotics, first some time at the US office and then participating in the main development in Västerås. Steve's responsibilities at ABB Robotics have included many aspects of control, dynamic models, and software engineering. He is now a chief engineer at ABB Robotics in Gothenburg where he works with so called virtual robots/controllers, digital factories, and the Robot Studio product.

In 1992, Ola Dahl presented his thesis on constrained robot control with interesting ideas on trajectory generation. In the same year, Lars Nielsen left our group to take up a position as Professor in vehicular systems at Linköping University. Soon after, eager to get industrial experience and to try other fields of control, Ola left the department to work as an control systems consultant. In the late '80s, Gunnar Sparr continued research in computer vision that had started and, in due course, he formed his own, very successful, group on image processing at Department Mathematics. This group has maintained an active interest in robotic vision, and recent approaches include an increased amount of collaboration between our departments.

Even though the Irb-6 robot was extensively used in teaching and research, it was rather limited in terms of working range, degrees of freedom, and dynamic properties. In 1990, Klas therefore started NUTEK projects and used his ABB contacts to get a more modern robot, which first was rented and then bought. It was an Irb-2000 with an S3 control system. Earlier at ABB, Klas played a leading role in the early

design of the S3 controller, so also in this case he knew the internal interfaces, and started a major effort with Rolf Braun in reconfiguring also the new, bigger robot to permit advanced control experiments.

The robotics laboratory now included two robots placed adjacently to one another. Proposed by Lars, the two robots where named Stor-Klas and Lill-Klas (Big Klas and Little Klas after a Scandinavian comics strip), to honor the one that spent, perhaps too many, weeks on the reconfiguration. At this time, however, there was a decreasing interest in robotics within the department. On a longer term, there was even the risk of the laboratory being closed down. But with a genuine interest in robotics, Rolf Johansson and Klas Nilsson decided to continue and to expand. New projects were defined and further efforts in widening the scope of the research was made, as described in the sequel.

7.3 The Integrated Robotics Laboratory at Lund (1992–)

The robotics group of Department Mechanical Engineering, headed by Prof. Gunnar Bolmsjö and dating back to 1987, originally had a orientation towards manufacturing gradually developed towards a strong interest in software tools for application programming-in particular, off-line programming and simulation environments. At Department Industrial Electrical Engineering and Automation, there were activities in electrical drives and sensor technology. At that department, Gunnar Lindstedt was working with ultrasonic sensors for object recognition in robotic work cells, and he also helped with programmable hardware for the Irb-2000 interfaces. Over the years, the collaboration with Gunnar and Prof. Gustaf Olsson, previously with Department of Automatic Control, has been very rewarding.

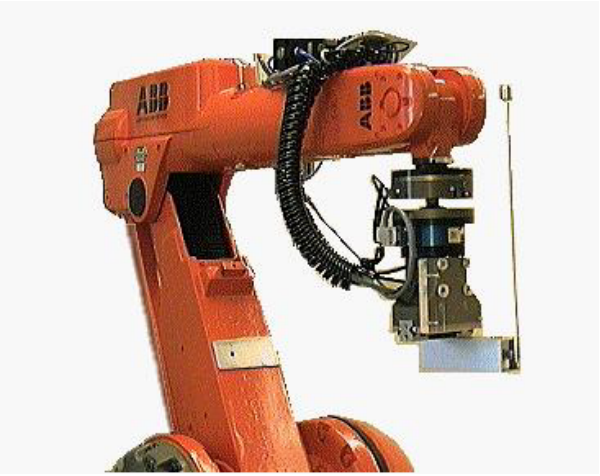
In 1993, coordination of the groups was stimulated by funding from the Nutek program "Mobile Autonomous Systems" and Rolf Johansson was appointed as a coordinator. Anders Robertsson joined the group as a graduate student with a strong background in nonlinear control. Magnus Olsson and Krister Brink and, later, Per Cederberg participated as graduate students at Department Mechanical Engineering. Efforts to merge ideas on feedback control and off-line programming were started.

Jan Peter Meeuwse, Bart Hendricks, Olof Laurin made master theses in the Robotics Laboratory under guidance of Klas Nilsson and Rolf Johansson. The research got support from ABB Robotics under the direction of Dr. Torgny Brogårdh. One memorable event in 1996 was the visit of an evaluation committee from Nutek headed by the Program Manager John Graffman and with the veteran robot engineer Joseph Engelberger, retired manager and designer of Puma robots.

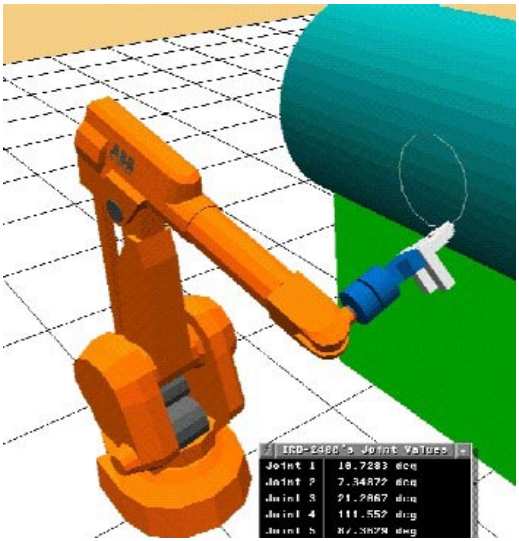
For all robotic activities, real-time systems have been an important part of the research, and robot control appear to be among the most realistic case of industrial control implemented within the department. The aim for more flexible and open real-time control systems inspired to new solutions for dynamic linking, as proposed by Anders Blomdell and Klas Nilsson. Another flexible solution, the so called Pålsjö system permitting on-line changes of control software, was developed by Anders Blomdell and Johan Eker. Efforts by Klas Nilsson, Anders Blomdell, Johan Eker, and Olof Laurin provided solutions for dynamic linking which was a prequisite to on-line change of control. Anders Blomdell and Johan Eker developed Pålsjö for programming of tasks of control applications. Albert-Jan Baerveldt with his PhD from ETH, Zürich, Switzerland and Angel Valera with a PhD from UP Valencia, joined the group as postdoc scientists in 1993 and 1998, respectively. Norberto Pires with a PhD from Coimbra, Portugal, has been on research visit to the Robot Laboratory at a couple of different occasions, latest in 1999. The software effort eventually permitted the laboratory to be open, not only to hardware or software components, but also to scientists.

In 1996, Klas Nilsson defended his PhD thesis "Open Robot Control Architectures". Based on the observation that robots are distinguished from other types of machinery mainly on the basis of their programmability and ability to be adaptable to different tasks, the thesis had a strong emphasis on software engineering. The structure of early control systems, however, limited the applicability of robots, thus leaving many human-unfriendly operations to be performed manually. This thesis took a problem-oriented approach, without enforcing use of formal methods. Considering industrial demands, such as computing efficiency and simple factory-floor operation, a layered system architecture and

technical solutions to accomplish it are proposed. A notion of *user views* was introduced as the basis for definition of the layers, the layers supporting programming on levels ranging from implementation of motor control and up to end-user programming. An experimental platform, built around industrially available robots, was developed. Specially developed hardware interfaces and reconfigurations of the original (ABB) system were made to permit control and programming even for lowest-level motion control.



Run-time efficiency within the proposed open and layered system was achieved by a novel concept called actions. Actions were pieces of compiled code that, by use of certain compiling and linking techniques, could be passed as parameters between the layers. The required interplay between application specific programs and built-in motion control could therefore be accomplished. A number of case studies and results from ongoing experimental evaluation indicated that the proposed control system principles were very useful also in industrial contexts.



After Klas Nilsson's dissertation in 1996 and after some months with ABB Robotics, Klas joined the Department Computer Science as an assistant professor. In this capacity, he has maintained an active interest and activity in the laboratory. His postgraduate orientation towards real-time systems and safe programming languages, in particular Java technology, is an important asset. The collaboration between control and computer science is active and increasing.

Anders Robertsson's PhD thesis entitled "On Observer-Based Control of Nonlinear Systems" (1999) addressed problems of observer design and observer-based control for nonlinear systems, the deterministic continuous-time systems being in focus. A generalization to the observer-backstepping method with the controller designed with respect to estimated states was treated. Moreover, velocity observers with application to mechanical manipulators vehicles were presented. Anders continued his postgraduate career in Robotics Laboratory with his participation in projects on robotic force control.

In the year 2000, an Irb-2400 robot with an S4C+ controller was kindly made available by courtesy of ABB Robotics. Modifications of the system was this time made together with ABB at their site, maintaining

compatibility with the existing system. This development was mainly accomplished by Anders Robertsson (with nicknames Robotsson and Robban) spending many weeks in Västerås. Following the custom of naming the robot to honor the one who made most of the system engineering, the robot got the nickname "Robban". The new robot was placed in the space belonging to the Department Mechanical Engineering, a tangible example of the integrated and multidisciplinary profile of the robotics activities as formed by a relatively small group of people for further successful robotics research in the new millennium.

7.4 Research Impact and Industrial Collaboration

ABB Robotics has been remarkably successful and has had for significant time more than half of the world market in heavy robot equipment with a particularly heavy market penetration in car manufacturing. As for applications, ABB robot systems have proved competitive in arc welding, spot welding, gluing, material handling, and machine tending in increased capacity, enhanced quality and flexibility.

Some of the people behind this success have a background from our department. Hans Skoog who later became prominent in engineering and management at ABB Robotics made his master thesis in 1967 in the area of adaptive control.

The S4C+ is the latest in a long line of ABB robot controllers and it is designed to match the physical capabilities of the robot range. The S4C+ tries to optimize cycle time and path accuracy and it tries to be readily integrated into factory automation plan. The S4C+ is a compact, configurable, modular system physically organized with a control cabinet and control pendant are used for all ABB robots. There are many aspects in common between the work of Klas Nilsson and the current ABB approaches, and the work on open robot control system architectures provides appropriate such techniques.

Currently, cooperation with ABB continues with Klas and Anders frequently visiting for on-site system R&D. We are happy to stay in touch with the friendly atmosphere at ABB Robotics, and in particular,

we are very grateful for the way Dr. Torgny Brogårdh promotes research and long-term development issues within ABB.

7.5 Acknowledgment of Project Support

Among important sources of financial support:

- Lund Research Programme in Autonomous Robotics (Nutek-Mobile Autonomous Systems
- Open Control Architectures (Nutek-Complex Technological Systems)
- Sensor-based Integration and Task-level Programming (Nutek-Complex Technological Systems)
- Nutek-RAS: Open Control Systems, Off-line Programming and Real-Time Control
- Nutek-KTS: Force control

The Nutek projects have long been very helpful to our Robotics Laboratory in their support of research with intellectual quality and industrial application.

7.6 References on Robotics Research

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Johansson, Rolf: "Adaptive control of robot manipulator motion." *IEEE Transactions on Robotics and Automation*, **6:4**, pp. 483–490, 1990.

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Johansson, Rolf, and M. W. Spong: "Quadratic optimization of impedance control." In *Proc. IEEE Int. Conf. Robotics and Automation*, pp. 616–621, San Diego, California, May 1994.

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Mårtensson, E.: "Aktiv dämpning av svängningsmoder i en robotarm," (Active damping of oscillation modes in a robot arm). Master thesis TFRT-5359, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 1986.

Meeuwse, Jan Peter: "Algorithms and tools for control of flexible servo systems." Master thesis ISRN LUTFD2/TFRT--5531--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, July 1995.

Nielsen, Lars: *Simplifications in Visual Servoing*. PhD thesis TFRT-1027, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1985.

Nilsson, Klas: "Analysis and synthesis of the dynamics of an industrial robot." Master thesis ISRN LUTFD2/TFRT--5292--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 1983.

Nilsson, Klas: *Industrial Robot Programming*. PhD thesis ISRN LUTFD2/TFRT--1046--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 1996.

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

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

Skoog, Hans: "Analys av Margolis Leondes adaptiva reglersystem," (Analysis of Margolis Leonde's adaptive systems). Master thesis ISRN LUTFD2/TFRT--5021--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, October 1976.

8. Dissertations

Three PhD theses were defended by Anders Wallén, Hélène Panagopoulos, and Erik Möllerstedt; and one Lic Tech was completed by Anton Cervin.

The abstracts are presented here in chronological order.

Tools for Autonomous Process Control

Anders Wallén
PhD dissertation, February 18, 2000

Opponent: Prof. Guy Dumont, University of British Columbia, Vancouver, Canada. Committee: Prof Mogens Blanke, Dept. of Control Engineering, Aalborg University, Denmark; PhD Lars Pernebo, ABB Automation Products, Malmö, Sweden; PhD Stefan Rönnbäck, AssiDomän, Piteå, Sweden.

There is an ongoing trend towards higher automation level in process control systems. The reason for introducing more autonomy is to make the operators work more efficiently and to extend the region where the plant can be operated satisfactorily without the operator's assistance.

This thesis treats different aspects of autonomous process control. The focus is on autonomy at the local control loop level. A list of desired functionality for an autonomous single loop controller is presented. This list consists of methods for initialization, assessment of basic process features, selection and tuning of on-line controller, monitoring of the on-line control performance, and fault diagnosis. Implementation aspects and software architecture of an autonomous single loop controller are also discussed. In particular, sequential control using the graphical language Grafchart is studied.

An interactive tool for preliminary assessment of the process dynamics is presented. A simple dynamical model, possibly combined with a static non-linear function, can easily be obtained from one or more step response experiments. The model can be used for calculating parameters for a PI or PID controller.

A new method for automatic tuning based on relay feedback is developed. A relay with time-varying hysteresis is used in order to achieve excitation over a large frequency interval. An estimation of the frequency response of the process is obtained by frequency domain identification. This estimation is used together with optimization methods for robust PI and PID controller design.

A simple strategy for fast set point response is presented. It mimics what experienced process operators often do manually to obtain fast set point step responses with no overshoot. The strategy consists of a short sequence of steps in the control signal. Conditions for good switching times are given. These conditions can be applied with varying degrees of process knowledge.

PID Control Design, Extension, Application

Hélène Panagopoulos
PhD dissertation, February 24, 2000

Opponent: Docent Håkan Hjalmarsson, Royal Institute of Technology, Stockholm, Sweden. Committee: Prof. Alina Besancon-Voda, Laboratoire d'Automatique de Grenoble, France; PhD Per Persson, Volvo, Gothenburg, Sweden; Prof. Bengt Lennartsson, Institute of Automatic Control, Chalmers, Gothenburg, Sweden.

This thesis considers the design of PID controllers,
the extension of these controllers to improve their performance, and the applications of these design methods to industrial processes.

New tuning methods for PI and PID controllers have been presented. These methods uses a model of the process to be controlled, given as a transfer function. The methods captures essential requirements of a control system, such as: load disturbance response, robustness with respect to model uncertainties, measurement noise response, set point response. The primary design goal of the proposed design methods are to achieve good rejection of a load disturbance with the constraint on robustness to guarantee the stability of the closed loop system.

The use of PID control have been extended to bridge the gap between it and the theoretical H_∞ control. It is shown how the robustness constraint of the proposed design methods for PI and PID controllers should be chosen to guarantee that the weighted H_∞ norm of the transfer function from load and measurement disturbance to process inputs and outputs is less than a specified value γ. A new way o determine for which class of system a PID controller will be stabilizing is also presented.

Furthermore, the use of PID control have been extended o handle processes with undamped modes. A modular approach has been taken, where an active control system has been designed, which consists of an all-pass filter and a bandpass filter. To determine the parameters of these two filters the only information needed is a few characteristics of the process frequency response.

The proposed design methods for PI and PID controllers have been evaluated in a benchmark for control of steam generator water level in a power plant, and at the pulp and paper company Modo Paper, in Husum, Sweden.

Towards the Integration of Control and Real-Time Scheduling Design

Anton Cervin
Lic Tech dissertation, May 26, 2000

Opponent: Prof. Gerhard Fohler, Mälardalens Högskola, Västerås, Sweden.

The thesis deals with scheduler and controller co-design for real-time control systems. The overall goal is higher resource utilization and better control performance. One goal is to minimize the performance loss due to jitter and control delays. Another goal is to relax the nominal requirements on hard deadlines and fixed worst-case execution times. A third goal is to provide a co-simulation environment for real-time control systems.

Sub-task scheduling of the two main parts of a control algorithm is investigated. A heuristic, iterative deadline-assignment algorithm is given that attempts to minimize the computational delay for a set of control tasks.

A simulator for co-design of real-time control systems is presented. It facilitates simultaneous simulation of real-time task execution and continuous plant dynamics. The simulator makes it possible to evaluate the true, timely behavior of control algorithms, and to evaluate scheduling policies from a control performance perspective.

A feedback scheduler for control tasks with varying execution times is developed. Using a combination of feedback and feedforward, the feedback scheduler attempts to keep the CPU utilization at the desired level by manipulating the sampling periods of the controllers. A case-study with a set of hybrid control tasks for a set of double-tank processes is presented.

Dynamic Analysis of Harmonics in Electrical Systems

Erik Möllerstedt
PhD dissertation, November 10, 2000

Opponent: Prof. David Hill, University of Sydney, Australia. Committee: PhD Jorge Mari, Adtranz, Västerås, Sweden; PhD Magnus Fontes, Lund Institute of Technology, Lund, Sweden; Mr. Gunnar Asplund, ABB, Ludvika, Sweden.

Frequency domain analysis and design of power systems is complicated in the presence of harmonics, switching dynamics, nonlinearities, unbalances, and for systems with mixed ac/dc dynamics. The reason is that linearization of the system does not lead to a time invariant system, but a system with periodically time varying dynamics, which implies that there is coupling between different frequencies. Often one has to rely on simplifying assumptions and simulation.

The thesis uses linear periodic (LTP) models to analyze power systems. The harmonic transfer function (HTF) for LTP systems is introduced. Using the HTF, the system can be treated as an infinitely dimensional linear time invariant system, which means that the system, under certain convergence conditions, can be analyzed using the well developed theory for LTI systems.

The thesis contains four papers with power system applications. Paper I describes the modeling and analysis of networks including components with switching dynamics, such as diodes and thyristors. An algorithm for parameter estimation from experimental data is presented. Papers II and III treats modeling and analysis of single-phase railway systems. The modeling of the locomotives is performed in collaboration with industry. Paper IV treats analysis and control aspects of a converter for grid connection of a micro-turbine used for distributed power generation. This is a three-phase application done in collaboration with the industry.

9. Honors and Awards

The paper "Robust Automatic Tuning of an Industrial PI Controller for Dead-time Systems" by **Ari Ingimundarson** and **Tore Hägglund** was distinguished as one of the best papers in the evaluation process of the International Program Committee of IFAC Workshop on Digital Control: Past, Present and Future of PID, Terrassa (Spain), in April 2000.

Kuan Luen Ng, Master Student, received the Terry Whodcoat Prize awarded to the best exchange student in the graduating year. The prize was given at Imperial College on the day of graduation, October 25. Master thesis advisor was **Rolf Johansson**.

The IEEE Board of Directors elected **Anders Rantzer** to IEEE Fellow effective 1 January 2001 with the following citation: "For contributions to the theory and computational analysis of uncertain and nonlinear systems".

Karl-Erik Årzén was appointed as Professor in Automatic Control from June 1, 2000.

10. Personnel and Visitors

Personnel

During 2000 the following persons have been employed at the department. The list shows the *status of December 2000* if nothing else is mentioned.

Professors

Karl-Erik Årzén *(from June 1)*
Karl Johan Åström (emeritus)
Bo Bernhardsson
Per Hagander
Tore Hägglund
Rolf Johansson
Anders Rantzer
Jan Sternby (adjunct 20%) *(until January 31)*
Björn Wittenmark

Associate Professors

Mats Åkesson *(until June 30)*
Karl-Erik Årzén *(until May 31)*
Johan Eker
Anders Robertsson

Research Engineers

Leif Andersson
Anders Blomdell
Rolf Braun

Guest Professor

Andrey Ghulchak

Holder of a scholarship

Stéphane Velut

PhD Students

Johan Bengtsson
Anton Cervin
Lena de Maré
Jonas Eborn
Mattias Grundelius
Magnus Gäfvert
Sven Hedlund
Dan Henriksson *(from December 1)*
Ari Ingimundarson
Charlotta Johnsson *(until March 15)*
Bo Lincoln
Erik Möllerstedt
Hélène Panagopoulos *(until July 31)*
Mikael Petersson
Rasmus Olsson
Henrik Sandberg *(from January 3)*
Stefan Solyom
Hubertus Tummescheit
Anders Wallén *(until April 30)*

Secretaries

Eva Dagnegård *(absent)*
Britt-Marie Mårtensson
Eva Schildt
Agneta Tuszyński (part time)

Visiting Scientists

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

Angel Valera *Jan 10–Feb 10, 2000*
University Politecnica de Valencia, Spain

Guy Dumont *Feb 17–20, 2000*
University of British Columbia, Vancouver, Canana

Alina Besancon-Voda *Feb 22–25, 2000*
Lab d'Automatique de Grenoble-ENSIEG, Saint Martin d'Heres, France

Michael Schinkel *May 1–31, Aug 1–Nov 30, 2000*
University of Glasgow, Great Britain

Romeo Ortega *May 3–6, 2000*
CNRS-ESE, France

Raffaello D'Andrea *June 12–14, 2000*
Cornell University, USA

Jim Rawlings *June 14–21, 2000*
University of Wisconsin-Madison, USA

Geir Dullerud *Aug 21, 2000*
University of Illinois, USA

Pablo Parrilo *Aug 27–Sep 27, 2000*
Caltech, Pasadena, USA

John Doyle *Sep 6–10, 2000*
Caltech, Pasadena, USA

Per-Olof Gutman *Sep 28–29, 2000*
Technion Israel Institute of Technology, Haifa, Israel

David Hill *Nov 6–11, 2000*
Sydney University, Sydney, Australia

Visiting Students

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

Michael Grebeck (B) *July 1999 – July 2000*
Caltech, Pasadena, USA

Luca Caputo (E) *September 1999 – September 2000*
Universita Degli Studi, Firenze, Italy

Stéphane Velut (E) *January – December 2000*
Ecole Nationale Superieure d'Ingenieurs Electriciens de Grenoble, Grenoble, France

Kuan Luen Ng (E) *January – December 2000*
Imperial College, London, Great Britain

Franck Ruffier (E) *January – August 2000*
Institut National Polytechnique de Grenoble, France

Alessandro Pontremoli (E) *April – September 2000*
Universita Degli Studi Di Roma La Sapienza, Italy

Zhimin Zhang (B) *from August 2000*
Beijing Institute of Petrol Chemical, Beijing, China

Susana Santos (E) *August 2000 – April 2001*
Universidad de Valladolid, Spain

Luis Manuel Conde Bento (E) *from September 2000*
Universidade de Coimbra, Portugal

Antonio Gomez Perez (E) *from October 2000*
Universidad Politecnica de Cartagena, Spain

Duarte Mendonca (E) *from October 2000*
Universidade de Coimbra, Portugal

Domenico Scalamogna (E) *from October 2000*
Universita degli Studi, Firenze, Italy

11. Staff Activities

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

Åkesson, Mats

PhD in 1999. His main research interest is modeling and control of biotechnical processes. During the spring, he was working on control of *E. coli* cultivations in a joint project with Pharmacia & Upjohn. He was also engaged in a research collaboration with the Department of Biotechnology, Lund University. In June 2000, he left the department to work for Biotecnol SA, Portugal.

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.

Årzén, Karl-Erik

Professor, PhD 1987. Joined the department in 1981. His research interest are real-time systems, Petri nets and Grafcet, fuzzy control, and monitoring and diagnosis.

Project leader for the SSF/ARTES project on integrated control and scheduling, for the NUTEK project on programming languages for real-time systems, and for the TFR/SSF industrial PhD project on industrial aspects of monitoring and diagnosis. Member of the steering committee of LUCAS (Center for Applied Software Research). During the year he

has personally primarily been involved in the EU FAMIMO project on engine control, in the SSF/ARTES project, and in the formation of LUCAS. He is partly or fully involved in the supervision of five PhD students.

Bengtsson, Johan

MSc, graduate student since April 1999. He is interested in system identification, and he is working in cooperation with Volvo Technical Development on driver models. During the year Johan was teaching assistant in the Automatic Control basic course.

Bernhardsson, Bo

PhD 1992, Docent in 1998, and Professor in December 1999. Bo works in the areas of linear system theory, real-time control, communication networks, motion control, hybrid control, and applied mathematics. he is project leader for the projects on "Analysis of Power Quality" and "Motion Control" described in Section 5. During this year he (co)-supervised the PhD students Cervin, Grundelius, Gäfvert, Möllerstedt, Lincoln, and Sandberg on topics described in Section 5. During spring he held the undergraduate course in Nonlinear Control and Servo-systems and the PhD course in Synthesis. Since April 2000 he is the chairman of the board of Industrial Management and Engineering.

Blomdell, Anders

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

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

Lic Tech in May 2000, graduate student since May 1998. Anton's research topic is real-time systems, and he is involved in the SSF/ARTES project "Integrated Control and Scheduling". During 2000 he has been teaching assistant in Computer-Controlled Systems and in Real-Time Systems.

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 on control of *E. Coli* cultivations and other microorganisms. During 2000 she has been teaching assistant in the course Process Control and in Automatic Control, basic course.

Eborn, Jonas

Lic Tech, graduate student since 1995. Interested in computer aided control engineering, physical system modelling and numerical analysis. He is working in the NUTEK programme "Complex Technical Systems" and is also involved in the collaboration with Sydkraft AB. During the spring term 2000 he was teaching assistant in the graduate course Physical Modelling of Dynamical Systems and during the autumn in the basic control course. He is also responsible for the seminar schedule of the department.

Eker, Johan

During 2000 Johan Eker worked as a researcher within the LUCAS project. His main focus was on wireless control application using Bluetooth. This included several student projects and one master thesis project. To facilitate experiment with Bluetooth a Java Bluetooth stack called Harald was implemented. Besides the work on Bluetooth control

applications he also spent time on the ARTES Integrated Control & Scheduling project together with Anton Cervin. During the fall he was also teaching assistant and lecturer in the course Real-Time Systems.

Gäfvert, Magnus

MSc, graduate student since July 1996. Magnus is interested in topics on distributed control and Real-Time Systems. Current work deals primarily with automotive applications. During he year he has worked on a case study on a truck braking system, provided by Volvo Technological Development within the NUTEK project DICOSMOS. Magnus spends one week per month at Volvo TD in Gothenburg. He has also worked with control of GDI engines, a benchmark problem provided by Siemens Automotive, within the EU Esprit project FAMIMO. His previous work includes modeling, analysis and control of systems with friction. He is also involved in the development of the computer based interactive tools for control education, ICTools. During the year he was a teaching assistant in System Identification and Real-Time Systems. He also acted as advisor for Peter Odebjer, Johan Svahn and Wael Chatila in their respective Master's Thesis work.

Ghulchak, Andrey

PhD, Guest Lecturer and Researcher since September 1998. His research interest contains analysis and design of robust control systems, constrained H_∞ and multi-objective control, systems with delays as well as the general operator theory and functional analysis. He develops methods and MATLAB software for robust controller design using convex optimization.

In 2000 he has been a teaching assistant in the courses Linear Systems I and Basics of Robust Control for PhD students. He has participated in Reglermöte (Uppsala) and the IEEE CDC Conference (Sydney).

Grundelius, Mattias

Graduate student since January 1996. He is interested in control in general and works with optimal control of packaging machines in a collaboration with Tetra Pak Research & Development AB. He has

also been teaching assistant in the Computer-Controlled Systems, Real-Time Systems and Adaptive Control courses.

Hagander, Per

Professor, PhD (1973). Per has been with the department since 1968 and works with linear system theory and with applications in biotechnology and medicine. He is the director of studies at the department and also the department contactperson for industrial liasons. Starting Dec 2000 he is the LTH dean of international affairs. Per is responsible for the course Computer Controlled Systems.

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

On July 24 his first grandchild, Tom, was born.

Hägglund, Tore

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

Main research activities during the year have been design of PID and dead-time compensating controllers, and development of supervisory functions for process control. During the year he got a patent on his ratio controller “The Blend Station”.

Hedlund, Sven

Lic Tech, graduate student since September 1997. His main research interest is analysis and synthesis of hybrid systems and he is involved in the ESPRIT-project H^2C, Heterogeneous Hybrid Control. During 2000, Sven has been a teaching assistant in the basic undergraduate course in Automatic Control.

Ingimundarson, Ari

Graduate student since November 1998. His research interests include process control, dead-time compensation and performance monitoring. Ari has been a teaching assistant in two undergraduate courses: 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 and in robotics and nonlinear systems. He is coordinating director for a NUTEK-sponsored research program "Lund Research Programme in Autonomous Robotics" with cooperation partners from Dept Production and Materials Engineering and Dept Industrial Electrical Engineering and Automation and industrial partners. He has industrial cooperation with ABB Robotics, ABB Corporate Research and Volvo Technical Development. He is responsible for the two courses System Identification and Nonlinear Control and Servo Systems in the engineering program.

Together with Dr. Månsson he leads research at the Vestibular Laboratory, Dept. Otorhinolaryngology, Lund University Hospital.

Lincoln, Bo

MSc, graduate student since February 1999. He and his advisor Bo Bernhardsson are working on control problems when wireless networks (such as Bluetooth) are involved. Both the problem of controlling the network for e.g. low-delay routing, and the problem of using the network in control loops are considered. He has been a teaching assistant for the course in Nonlinear Systems twice.

Mårtensson, Britt-Marie

Secretary at the department since 1974, responsible for the maintenance of the department library, ordering books and journals. She handles the mail and office supplies for the department. She also works with scanning and drawing figures with the computer.

Möllerstedt, Erik

PhD in November 2000, Lic Tech, graduate student since 1994. Erik is interested in analysis and control of nonlinear and switching systems with applications in power systems. He is working within the Elforsk project “Analysis of Electric Power Quality in Distributions and Loads”. From February to April 2000, he was a guest researcher at ABB corporate Research in Baden-Dättwil,Schweiz, working with modelling and control of distributed power generation units. The rest of the time this year he has spent on his thesis “Analysis of Modern Power Systems - a Linear Time Periodic Approach”, which was successfully defended in November 2000.

Olsson, Rasmus

MSc, graduate student since 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. He has also been teaching assistant in the undergraduate course Automatic Control.

Panagopoulos, Hélène

PhD in February 2000, graduate student since September 1995. Her research interest concern both theory and applications. The major research area is in the field of PID-controller design. Hélène left the department in July to work with Metsä-Serla Corporation in Örnsköldsvik.

Petersson, Mikael

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

The research has been focused on control structure assessment and particular work has been carried out on feedforward control structure, with a patent pending. Currently, the ideas are being implemented in real-time Java for use on both virtual and laboratory processes.

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 design of control systems. In particular, he develops methods for treatment of uncertainty and nonlinearities using convex optimization.

Anders Rantzer is responsible for the basic course in Automatic Control for electrical engineers and supervises the PhD students Eborn, Hedlund, Möllerstedt, Sandberg, Solyom, and Tummescheit. He is associate editor of two journals and serves on two committees within the university. In May 2000 he organized a workshop in Lund on hybrid control and automotive applications. He gave two plenary lectures and two invited presentations at conferences and workshops.

Robertsson, Anders

Researcher, 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 under the NUTEK Program "Complex Technical Systems" in collaboration with ABB Robotics.

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 the many visitors at the department.

On July 29 her first grandchild, Samuel, was born.

Solyom, Stefan

MSc, graduate student since 1999. His main research interests are in piecewise linear systems. In 2000 he joined the H2C project (ESPRIT project on Heterogeneous Hybrid Control) and is engaged in research collaboration with DaimlerChrysler AG, Germany on an ABS system. During 2000 he was teaching assistant in the courses System Identification and Adaptive Control, in the engineering curriculum.

Tummescheit, Hubertus

Graduate student since 1996, graduate student in Lund since 1998. Interested in physical system modelling, modelling language design and numerical analysis. He is working in the NUTEK programme "Complex Technical Systems" and is also involved in the collaboration with Sydkraft AB. Since 1997 he is a member of the Modelica Design Group, which became the non-profit Modelica Association this year. The goal of the Modelica Association is the active development of the Modelica modelling language. This year he was the local organizer of the Modelica 2000 workshop in Lund. From January to April he has been visiting the Scientific Research Lab of Ford Motor Company to support the evaluation of the Modelica language in a large scale industrial project. During 2000 he has been teaching assistant in one basic control course. He has also supervised a master thesis on modelling of an evaporative gas turbine plant with Modelica.

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, helping colleagues with writing letters, articles, and reports. Agneta is also responsible for Activity Report 2000 together with Karl-Erik Årzén.

Velut, Stéphane

MSc, graduate student since July 1999. Stéphanet's research topic is control of biotechnical processes. He is working together with Lena de Maré and Per Hagander on control of *E. coli* cultivations. He has has been a teaching assistant in the Automatic Control basic course.

Wallén, Anders

PhD, graduated from the department in February 2000 with a thesis entitled "Tools for Autonomous Process Control", which covers different aspects of increasing the degree of automation on the local control loop level. The three main topics in the thesis are: an interactive tool for process identification and design, a new method for automatic tuning

using relay feedback, and a simple strategy for fast set point response. Anders left the department for Ericsson Mobile Communications in May 2000.

Wittenmark, Björn

Professor in Automatic Control since 1989. He joined the department in 1966 and took his PhD in 1973. His main research interests are adaptive control, sampled-data systems, and process control. he is working within the projects “Timing Problems in Real-time Systems”. and “Center for Chemical Process Design and Control”. He is also chairman of the department.

External Assignments

Opponent and Member of Examination Committee

Karl-Erik Årzén: External opponent on the licentiate thesis by Mr. Thomas Thelin, Department of Communication Systems, Lund University, May 25. Member of the examination board of the Ph.D. thesis by Mr. Esa Falkenroth, Department of Computer Science, Linköping University, June 8. Member of the examination board of the Ph.D. thesis by Mr. Dominique Passaquay, LAAS, Toulouse.

Bo Bernhardsson: Member of examination committee for Mattias Nordin, KTH, February 25. Member of examination committee for Torbjörn Norlander, LuleåTekniska Universitet.

Tore Hägglund: External opponent for the licentiate "Evaluation and Tuning of PID Controllers" by Birgitta Kristiansson, Chalmers, Gothenburg, and the licentiate thesis "Automatic manufacture of fertilizing granules from burnt wood ash" by Thomas Svantesson, LTH, Lund. Member of the examination committee for the PhD thesis "Condition monitoring of control loops" by Alexander Horch, KTH, Stockholm.

Anders Rantzer: External opponent for PhD thesis by Mattias Nordin, KTH, February 25.

Björn Wittenmark: Member of examination board for the dissertation by Ola Wall at the Department of Solid Mechanics, LTH, December 15.

Board Member

Karl-Erik Årzén: Member of the board of ARTES, the Swedish real-time systems research network.

Bo Bernhardsson: Member of the board of directors of the programme in engineering physics, Chairman of the board of directors of the programme in Industrial Management and Engineering, and Member of the LTH-initiatives "De Yngres Råd" and "Forskningsfronten" all three at Lund Institute of Technology.

Tore Hägglund: Member of the Education Board of Computer Science and Technology, and deputy member of the Promotions Committee for FIME – physics, informatics mathematics and electrical engineering, both at Lund Institute of Technology.

Anders Rantzer: Appointed member of board of governors for IEEE Control System Society. Member of appointment committee and "Forskarutbildningsnämnd" at LTH.

Hubertus Tummescheit: Member of the Modelica Design Group. Organization of the Modelica 2000 workshop, October 23–24, Lund, Sweden.

Björn Wittenmark: Board member of Chematur AB until July 2000. Board member of Lunds Universitets Utvecklings Aktiebolag (Lund University Development Limited) until July 2000. Board member of Lunds Datacentral, LDC, (Lund University Computing Center). Swedish representative of European Union Control Association (EUCA) Council. Chairman of the committee for IFAC Control Engineering Practice Prize. Member of the Research Board – FIME Physics, Informatics, Mathematics, Electrical Engineering.

Book and Journal Editor

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

Bo Bernhardsson: Member of editorial board of the journal IEEE Transaction on Automatic Control.

Tore Hägglund: Associate editor for Control Engineering Practice.

Rolf Johansson: Associate Editor of the IEEE Control Systems Society Conference Editorial Board and Associate Editor of Int.J. Adaptive Control and Signal Processing.

Anders Rantzer: Associate editor of "System and Control Letters" and "Int. Journal of Robust and Nonlinear Control"

Björn Wittenmark: Optimal Control Applications & Methods, Journal of Forecasting, International Journal of Adaptive Control and Signal Processing, Springer series on Advances in Industrial Control, and Proceedings IEE, Control Theory and Applications.

Advisory Committees and Working Groups

Karl-Erik Årzén: Chairman of the IEEE Control System Society Technical Committee on Real-Time Control, Computing, and Signal Processing.

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

Member of International Program Committee (IPC)

Karl-Erik Årzén: Member of IPC for EuroMicro 2000, Stockholm, Sweden. Member of IPC for ADPM 2000, Germany. Member of IPC for IFAC Conference on New Technologies for Computer Control 2001, Hongkong.

Tore Hägglund: Member of the International Program Committees for the IFAC Workshop on Digital Control – Past, present and future of PID Control, Terrassa, Spain, and for the conference Control Systems 2002 in Stockholm.

Anders Rantzer: Member of the International Program Committee of the Fourth International Workshop on Hybrid Systems: Computation and Control (HSCC2001). Member of the program committee for the 2003 spring semester at the Institut Mittag-Leffler, Stockholm. Member of the steering committee of the International Symposium on Mathematical Theory of Networks and Systems (MTNS).

Other Assignments

Björn Wittenmark: Lecturer in the Distinguished Lectures Program of the IEEE Control System Society since 1993. Member of working group for planning of strategic research at Lund University.

12. Publications and Conference Contributions

16 journal papers, 32 conference contributions, 5 conference abstracts, and 3 technical reports have been published this year.

Journal Papers

Åström, Karl Johan: "Limitations on control system performance." *European Journal on Control*, **6:1**, pp. 2–20, 2000.

Åström, Karl Johan: "Model uncertainty and robust control." In *Lecture Notes on Iterative Identification and Control Design*, pp. 63–100, 2000.

Åström, Karl Johan, and Rodney D. Bell: "Drum boiler dynamics." *Automatica*, **36**, pp. 363–378, 2000.

Åström, Karl Johan, and Katsuhisa Furuta: "Swinging up a pendulum by energy control." *Automatica*, **36**, pp. 278–285, 2000.

Eker, Johan, Per Hagander, and Karl Erik Årzén: "A feedback scheduler for real–time control tasks." *Control Engineering Practice*, **8:12**, pp. 1369–1378, 2000.

Fransson, P-A., R. Johansson, A. Hafström, and M. Magnusson: "Methods for evaluation of postural control adaptation." *Gait and Posture*, **12**, pp. 14–24, 2000.

Hägglund, Tore, and Karl Johan Åström: "Supervision of adaptive control algorithms." *Automatica*, **36**, pp. 1171–1180, 2000.

Johansson, Rolf, Anders Robertsson, Klas Nilsson, and Michel Verhaegen: "State-space system identification of robot manipulator dynamics." *Mechatronics*, **10**, pp. 403–418, 2000.

Lefeber, E., A. Robertsson, and H. Nijmeijer: "Linear controllers for exponential tracking of systems in chained form." *International Journal of Robust and Nonlinear Control: Special issue on Control of Underactuated Nonlinear Systems*, **10:4**, pp. 243–264, apr 2000.

Möllerstedt, Erik, and Bo Bernhardsson: "Out of control because of harmonics – an analysis of harmonic response of an inverter train." *Control Systems Magazine*, 2000.

Panagopoulos, H., and K. J. Åström: "PID control design and H_∞ loop shaping." *Int. J. Robust Nonlinear Control*, **10**, pp. 1249–1261, 2000.

Rantzer, A., and M. Johansson: "Piecewise linear quadratic optimal control." *IEEE Trans. on Automatic Control*, 2000.

Savaresi, Sergio, and Björn Wittenmark: "Rejection of narrow-band disturbances subject to uncertain time-delays." *Int. J. Adaptive Control and Signal Processing*, **14**, pp. 39–49, 2000.

Tummescheit, Hubertus: "Object-oriented modeling of physical systems, part 11." *Automatisierungstechnik*, **48:02**, 2000. In German.

Tummescheit, Hubertus: "Object-oriented modeling of physical systems, part 12." *Automatisierungstechnik*, **48:04**, 2000. In German.

Tummescheit, H., and M. Tiller: "Object-oriented modeling of physical systems, part 17." *Automatisierungstechnik*, **48:12**, 2000. In German.

Conference Papers

Åkesson, Mats, and Per Hagander: "A simplified probing controller for glucose feeding in *Escherichia coli* cultivations." In *The 39th IEEE Conference on Decision and Control*, vol. 1, pp. 4520–4525, December 2000.

Årzén, Karl-Erik, Anton Cervin, Johan Eker, and Lui Sha: "An introduction to control and scheduling co-design." In *Proceedings of the 39th IEEE Conference on Decision and Control*, Sydney, Australia, December 2000.

Åström, Karl Johan: "Control problems in paper making - revisited." In *Preprints Control Systems 2000: Quantifying the Benefits of Process Control*, pp. 129–136, British Columbia, 2000.

Åström, Karl Johan, and Tore Hägglund: "Benchmark systems for PID control." In *IFAC Workshop on Digital Control – Past, present, and future of PID Control*, Terrassa, Spain, 2000.

Åström, Karl Johan, and Tore Hägglund: "The future of PID control." In *IFAC Workshop on Digital Control – Past, present, and future of PID Control*, Terrassa, Spain, 2000.

Barabanov, A., and A. Ghulchak: "Numerical solution to $\mathcal{H}^\infty$ control of multi-delayed systems via operator approach." In *Proceedings of IEEE Conf. on Decision and Control*, 2000.

Bauer, Olaf, and Hubertus Tummescheit: "Modeling of two-phase flows in modelica." In *Proceedings of the 3rd MATHMOD Conference, MATHMOD 2000*, Vienna, feb 2000. IMACS.

Bengtsson, J., A. Ahlstrand, K. Nilsson, A. Robertsson, M. Olsson, A. Heyden, and R. Johansson: "A robot playing scrabble using visual feedback." In *6th Int. IFAC Symposium on Robot Control (SYROCO 2000)*, Vienna, Austria, September 2000.

Carlson, J., R. Johansson, and S. B. Olsson: "Classification of electrocardiographic P-wave morphology." In *IEEE Conf. Decision and Control (CDC 2000)*, Sydney,Australia, dec 2000. Invited paper.

Cervin, Anton, and Johan Eker: "Feedback scheduling of control tasks." In *ARTES Real-Time Graduate Student Conference*, Gothenburg, Sweden, May 2000.

Eborn, Jonas, and Karl Johan Åström: "Modeling of a boiler pipe with two-phase flow instabilities." In *Modelica 2000 Workshop Proceedings*, pp. 79–88, Lund, October 2000. Modelica Association.

Eborn, Jonas, Hubertus Tummescheit, and Falko Wagner: "Development of a Modelica base library for modeling of thermo-hydraulic systems." In *Proceedings of the 41st SIMS Simulation Conference, SIMS'2000*, pp. 253–266, Copenhagen, September 2000.

Gäfvert, Magnus, Karl-Erik Årzén, and Lars Malcolm Pedersen: "Simple linear feedback and extremum seeking control of GDI engines." In *Proceedings of Seoul 2000 FISITA World Automotive Congress*, Seoul, Korea, June 2000.

Gäfvert, Magnus, Lars Malcolm Pedersen, Karl Erik Årzén, and B. Bernhardsson: "Simple feedback control and mode switching strategies for GDI engines." In *SAE 2000 World Congress*, Detroit, Michigan, USA, mar 2000. SAE paper 2000-01-0263.

Grundelius, Mattias: "Iterative optimal control of liquid slosh in an industrial packaging machine." In *Proceedings of the 39th IEEE Conference on Decision and Control*, Sydney, Australia, dec 2000.

Grundelius, Mattias, and Bo Bernhardsson: "Constrained iterative learning control of liquid slosh in an industrial packaging machine." In *Proceedings of the 39th IEEE Conference on Decision and Control*, Sydney, Australia, dec 2000.

Hägglund, Tore: "A new ratio control structure." In *IFAC Workshop on Digital Control – Past, present, and future of PID Control*, Terrassa, Spain, 2000.

Hedlund, Sven, and Anders Rantzer: "Hybrid control laws from convex dynamic programming." In *Proceedings of IEEE Conference of Decision and Control*, dec 2000.

Ingimundarson, Ari, and Tore Hägglund: "Closed-loop identification of first-order plus dead-time model with method of moments." In *ADCHEM 2000, IFAC International Symposium on Advanced Control of Chemical Processes*, Pisa, Italy, 2000.

Ingimundarson, Ari, and Tore Hägglund: "Robust automatic tuning of an industrial PI controller for dead-time systems." In *IFAC Workshop on Digital Control – Past, present, and future of PID Control*, Terrassa, Spain, 2000.

Johansson, Karl Henrik, and Tore Hägglund: "Control structure design in process control systems." In *ADCHEM 2000, IFAC International Symposium on Advanced Control of Chemical Processes*, Pisa, Italy, 2000.

Johansson, Rolf, and Anders Robertsson: "Covariance analysis, positivity and the Yakubovich-Kalman-Popov lemma." In *IEEE Conf. Decision and Control (CDC 2000)*, Sydney, Australia, dec 2000.

Lincoln, Bo, and Bo Bernhardsson: "Efficient pruning of search trees in lqr control of switched linear systems." In *Proceedings of the Conference on Decision and Control*, 2000.

Lincoln, Bo, and Bo Bernhardsson: "Optimal control over networks with long random delays." In *Proceedings of the International Symposium on Mathematical Theory of Networks and Systems*, 2000.

Möllerstedt, Erik, and Bo Bernhardsson: "A harmonic transfer function model for a diode converter train." In *IEEE Power Engineering Society Winter Meeting, Singapore*, 2000.

Nordberg-Karlsson, E., S. Ramchuran, A. Tocaj, M. Åkesson, P. Hagander, and O. Holst: "Fed-batch cultivation of *Escherichia coli* – strategies applied for production of thermostable enzymes." In *Third Meeting on Extremophiles as Cell Factories*, Graz, Australia, June 3–6 1999.

Olsson, Rasmus., and Karl Erik Årzén: "Exception handling in recipe-based batch control." In *Proc. of ADPM2000 The 4th International Conference on Automation of Mixed Processes.*, 2000.

Rantzer, Anders.: "On the dual of Lyapunov's second theorem." In *Proceedings of American Control Conference*, pp. 1186–1189, Chicago, 2000.

Rantzer, A., and P. Parrilo: "On convexity in stabilization of nonlinear systems." In *Proceedings of IEEE Conference of Decision and Control*, December 2000.

Robertsson, Anders, A. Valera, Klas Nilsson, and Rolf Johansson: "Online reconfiguration of real-time robot motion and force control." In *6th Int. IFAC Symposium on Robot Control (SYROCO 2000)*, Vienna, Austria, September 2000.

Tiller, M., C. Davis, H. Tummescheit, and N. Trigui: "Powertrain modeling with modelica." In *Prooceedings of IMECE2000, 2000 ASME International Mechanical Engineering Congress and Exposition*. ASME, November 2000.

Tummescheit, Hubertus, Jonas Eborn, and Falko Wagner: "Development of a Modelica base library for modeling of thermo-hydraulic systems." In *Modelica 2000 Workshop Proceedings*, pp. 41–51, Lund, October 2000. Modelica Association.

Conference Abstracts

Åkesson, M., S. Ramchuran, V. Martins, P. Hagander, and O. Holst: "Optimization of recombinant in protein production in an *E. coli*-based process with limited oxygen transfer." In *Abstract book of the 11th International Biotechnology Symposium and Exhibition (BIO2000), September 3–8, 2000, Berlin, Germany.*, pp. 4:297–299, September 2000.

Cervin, Anton, and Johan Eker: "Feedback scheduling of contol tasks." In *Proceedings of the 39th IEEE Conference on Decision and Control*, Sydney, Australia, December 2000.

Ghulchak, A., and A. Shiriaev: "Global stabilization of a class of nonlinear systems: An alternative description of the sufficient condition." In *Preprints of Reglermöte 2000*, pp. 56–60, 2000.

Panagopoulos, H., and T. Hägglund: "A new modular approach to active control of undamped modes." In *Reglermöte 2000, Uppsala University*, Uppsala, Sweden, 2000.

Sandberg, Henrik, and Erik Möllerstedt: "Harmonic modeling of the motor side of an inverter locomotive." In *Proc. of Reglermöte 2000*, Uppsala, Sweden, 2000.

Technical Reports

Claesson, V., Magnus Gäfvert, and M. Sandfridsson: "Proposal for a distributed computer control system in heavy-duty trucks." Dicosmos Internal Report 00-16, Computer Engineering, Chalmers University of Technology, 2000.

Peetre, J., and B. Bernhardsson: "Singular values of trilinear forms." Technical Report, Centre for Mathematics, 2000.

Sanfridsson, M., V. Claesson, and M. Gäfvert: "Investigation and requirements of a computer control system in a heavy-duty truck." Technical Report ISRN KTH/MMK–00/5–SE, Mechatronics Lab, Royal Institute of Technology, Stockholm, Sweden, 2000.

13. Reports

During this year 3 PhD theses and 1 Lic Tech thesis have been published. The abstracts are presented in Chapter 8. Also 24 master theses and 5 internal reports have been completed.

Dissertations

Cervin, Anton: *Towards the Integration of Control and Real-Time Scheduling Design*. Lic Tech thesis ISRN LUTFD2/TFRT--3226--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 2000.

Möllerstedt, Erik: *Dynamic Analysis of Harmonics in Electrical Systems*. PhD thesis ISRN LUTFD2/TFRT--1060--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 2000.

Panagopoulos, Hélène: *PID-Control. Design, Extension, Application*. PhD thesis ISRN LUTFD2/TFRT--1059--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, February 2000.

Wallén, Anders: *Tools for Autonomous Process Control*. PhD thesis ISRN LUTFD2/TFRT--1058--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, February 2000.

Master Theses

Åkesson, Johan: "Safe manual control of unstable systems." Master thesis ISRN LUTFD2/TFRT--5646--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 2000.

Andersson, Martin: "Matlab tool for rapid process identification and PID design." Master thesis ISRN LUTFD2/TFRT--5649--SE, De-

partment of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 2000.

Axelsson, Jens: "Supervision of computer equipment in ABB OperateIT using WMI." Master thesis ISRN LUTFD2/TFRT--5655--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, October 2000.

Caputo, Luca: "Control of energy storage device for rail vehicles." Master thesis ISRN LUTFD2/TFRT--5647--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, October 2000.

Davidsson, Peter, and Fredrik Hansson: "Communication between Matlab/Simulink and ABB advant control builder." Master thesis ISRN LUTFD2/TFRT--5639--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 2000.

Ervasti, Tomi, and Torkel Niklassson: "SDL programming of lego robots." Master thesis ISRN LUTFD2/TFRT--5648--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, October 2000.

Gagner, Johan, and Rickard Bondesson: "Adaptive real-time control of nonlinear throttle unit." Master thesis ISRN LUTFD2/TFRT--5638--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, February 2000.

Ghatak, Deb, and Johan Olofsson: "Design, implementation and verification using UML-RT in GSM radio base station 2000." Master thesis ISRN LUTFD2/TFRT--5641--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 2000.

Henriksson, Dan: "Observer-based impedance control in robotics." Master thesis ISRN LUTFD2/TFRT--5657--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 2000.

Ingimundarson, Ari: "Robust tuning procedures of dead-time compensating controllers." Master thesis ISRN LUTFD2/TFRT--5645--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 2000.

Johansson, Tommy: "Precise navigation for an agricultural robot." Master thesis ISRN LUTFD2/TFRT--5640--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, January 2000.

Klingberg, Anna: "Modelling and optimization of batch distillation." Master thesis ISRN LUTFD2/TFRT--5635--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, February 2000.

Larsson, Mathias: "Modeling and control in matlab for ABB's control builder." Master thesis ISRN LUTFD2/TFRT--5650--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, October 2000.

Levin, Jonas: "Sequential paging for moving mobile users." Master thesis ISRN LUTFD2/TFRT--5636--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, February 2000.

Liljenborg, Sara, and Anders Olsson: "Identify a surface with robot force control." Master thesis ISRN LUTFD2/TFRT--5656--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 2000.

Lindau, Filip: "Feedback control of plasma position in the EXTRAP-T2 fusion experiment." Master thesis ISRN LUTFD2/TFRT--5654--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 2000.

Ng, Kuan Luen: "Genetic programming in control theory: On evolving programs and solutions to control problems." Master thesis ISRN LUTFD2/TFRT--5642--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, June 2000.

Nilsson, Björn: "Experimental identification of the behavior of glass fiber bushing." Master thesis ISRN LUTFD2/TFRT--5651--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 2000.

Nilsson, Per, and Johan Brodin: "Implementing a wireless I/O unit using bluetooth." Master thesis ISRN LUTFD2/TFRT--5652--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 2000.

Odebjer, Peter, and Johan Svahn: "Linearization and nonlinear control in flight-controls and aeroelasticity for civil aircraft using MATRIXx." Master thesis ISRN LUTFD2/TFRT--5658--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 2000.

Olsson, Henrik: "Linear and neuro control strategies; some experimental results." Master thesis ISRN LUTFD2/TFRT--5643--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, June 2000.

Petersson, Niklas, and Martin Santesson: "Experimental slip-based road condition estimation." Master thesis ISRN LUTFD2/TFRT--5637--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, February 2000.

Pontremoli, Alessandro: "Modeling and control of a paper dryer section using modelica." Master thesis ISRN LUTFD2/TFRT--5653--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 2000.

Ruffier, Franck: "Control of a high voltage power supply for a traveling tube transmitter." Master thesis ISRN LUTFD2/TFRT--5644--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, February 2000.

Other Reports

Blomdell, Anders: "Eager evaluation considered harmful." Technical Report ISRN LUTFD2/TFRT--7590--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 2000.

Cervin, Anton: "The real-time control systems simulator—Reference manual." Report ISRN LUTFD2/TFRT--7592--SE, Department of

Automatic Control, Lund Institute of Technology, Lund, Sweden, April 2000.

Panagopoulos, Hélène, and Tore Hägglund: "A new modular approach to active control of undamped modes." Report ISRN LUTFD2/TFRT--7589--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, February 2000.

Persson, Patrik, Anton Cervin, and Johan Eker: "Execution-time properties of a hybrid controller." Report ISRN LUTFD2/TFRT--7591--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, April 2000.

Rantzer, Anders, and Eva Dagnegård: "Automatic Control 1999. Activity Report." Report ISRN LUTFD2/TFRT--4027--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, jun 2000.

Reports Available

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

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

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

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

14. Lectures by the Staff Outside the Department

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

Årzén, Karl-Erik

Simple Feedback Control and Mode Switching Strategies for GDI Engines, University of California, Berkeley, USA, February 29.

A Simulink Tool-box for Real-Time and Control Systems Co-Simulation, University of California, Berkeley, USA, March 1.

A Simulink Tool-box for Real-Time and Control Systems Co-Simulation, University of Illinois, Urbana-Champaign, USA, March 2.

Simple Feedback Control and Mode Switching Strategies for GDI Engines, University of Illinois, Urbana-Champaign, USA, March 3.

Simple Feedback Control and Mode Switching Strategies for GDI Engines, H2C Workshop, Lund University, Lund, Sweden, May 5.

Real-Time Control Systems, Spanish Summer School in Automatic Control, Almeria, Spain, May 29–31.

EC-funded Control Activities, Workshop on Future and Emerging Control Systems, Brussels, Belgium, June 19.

An Introduction to Control and Real-Time Sceduling Co-Design, Sydney, Australia, December 16.

Åström, Karl Johan

Event Based Sampling, Institute of Statistical Mathematics, Tokyo, Japan, January 8.

Modeling of Physical Systems, Tokyo University, Tokyo, Japan, January 11.

Friction Models and Friction Compensation, Tokyo University, Tokyo, Japan, January 12.

Tools for Modeling Physical Systems, COE conference on Supermechano Systems. Tokyo Institute of Technology, Tokyo, Japan, March 2.

Limitations of Control System Performance, Universidad Nacional de Educacion a Distancia, Madrid, Spain, March 28.

Black Boxes and White Noise - A perspective on Automatic Control, Universidad Nacional de Educacion a Distancia, Madrid, Spain, April 3.

The Future of PID Control, Terrassa, Spain, April 6.

Automatic Control - The Hidden Technology, EPFL, Lausanne, Switzerland, April 14.

Modeling of Physical Systems, EPFL, Lausanne, Switzerland, April 21.

Short Course on PID Control, EPFL Lausanne, Switzerland, April 25.

Automatic Control - The Hidden Technology, The S. S. Penner Distinguished Lectures in Aerospace and Mechanical Engineering, University of California, San Diego, USA, June 5.

Black Boxes and White Noice, Chalmers Institute of Technology, Gothenburg, Sweden, May 18.

Control Problems in Paper Making - Revisited, Control 2000, Victoria, Canada, May 2.

Fundamental limitations of Control Systems, University of British Columbia, USA, May 8..

Balancing and Steering a Bicycle, University of California, Santa Barbara, USA, October 6.

Stabilization of Bicycles, Department of Mechanical Engineering, University of California, Santa Barbara, USA, October 16.

Manual Control of Unstable Systems, Furuta Symposium, December 3.

Cervin, Anton

Feedback Scheduling of Control Tasks, ARTES Real-Time Graduate Student Conference, Gothenburg, Sweden, March 17.

Feedback Scheduling of Control Tasks, Invited paper, 39th IEEE Conference on Decision and Control, Sydney, Australia, December 15.

Eborn, Jonas

Thermo-Hydraulic Modelling and the Development of a Modelica Standard Library, Seminar at NUTEK Complex Technical Systems Conference, Lund. September 11.

Development of a Modelica Base Library for Modeling of Thermo-Hydraulic Systems, Seminar at Sims'2000 Simulation Conference, Copenhagen, Denmark. September 19.

Modeling of a Boiler Pipe with Two-Phase Flow Instabilities, Seminar at Modelica 2000 Workshop, Lund, Sweden. October 24.

Ghulchak, Andrey

Robust Controller Design Via Linear Programming, Division of Automatic Control, LiTH, Linköping, Sweden, September 7.

Grundelius, Mattias

Iterative Optimal Control of Liquid Slosh in an Industrial Packaging Machine, 2000 IEEE Conference on Decision and Control, Sydney, Australia, December 14.

Constrained Iterative Learning Control of Liquid Slosh in an Industrial Packaging Machine, 2000 IEEE Conference on Decision and Control, Sydney, Australia, December 15.

Hagander, Per

Control of Biotechnical Processes, Probing control of glucose feeding in aerobic cultivations, Nutek program conference, November 28.

A simplified probing controller for glucose feeding in Escherichia coli *cultivations,* CDC Sydney, Australia, December 15.

Reglering och feedprofiler – Testa pulsprogrammet i stor skala, Pharmacia, Strängnäs, Sweden, August 11.

Hedlund, Sven

Convex Dynamic Programming for Hybrid Systems, Signals and Systems, Chalmers University of Technology, Gothenburg, Sweden, November 17.

Hägglund, Tore

Process Control in Practice, Industrial course in Sundsvall, Sweden, January 26–27.

The Unmanned Factory, Invited lecture at Lund University Faculty Club, Lund, Sweden, February 2.

Process Control in Practice, Industrial course in Markaryd, Sweden, Februari 9–10.

Automatic Tuning and Gain Scheduling, Invited lecture at KTH, Stockholm, Sweden, February 16.

A New Ratio Control Structure, IFAC Workshop on Digital Control – Past, Present, and Future of PID Control, Terrassa, Spain, April 7.

Process Control in Practice, Industrial course in Tumba, Sweden, May 16–17.

Process Control in Practice, PhD course in the Nordic Energy Research Programme Lyngby, Denmark, September 13.

Supervision and detection, Invited lecture at Modo, Husum, Sweden, October 26.

Process Control in Practice, Industrial course in Tumba, Sweden, December 5–6.

Johansson, Rolf

Identification of Continuous-Time Models, Dept. Econometrics, Operations Research and System Theory, TU Vienna, Austria, April 12.

System Identification: Classical Methods, Dipartimento di Informatica e Sistemistica, Universita degli Studi di Napoli Federico II, Napoli, Italy, July 4.

System Identification: The Experimental Condition, Dipartimento di Informatica e Sistemistica, Universita degli Studi di Napoli Federico II, Napoli, Italy, July 4.

System Identification: Model Validation, Dipartimento di Informatica e Sistemistica, Universita degli Studi di Napoli Federico II, Napoli, Italy, July 5.

System Identification: Model Approximation, Dipartimento di Informatica e Sistemistica, Universita degli Studi di Napoli Federico II, Napoli, Italy, July 5.

System Identification: State-Space Methods, Dipartimento di Informatica e Sistemistica, Universita degli Studi di Napoli Federico II, Napoli, Italy, July 5.

System Identification: Recursive Identification, Dipartimento di Informatica e Sistemistica, Universita degli Studi di Napoli Federico II, Napoli, Italy, July 13.

System Identification: Continuous-Time Identification, Dipartimento di Informatica e Sistemistica, Universita degli Studi di Napoli Federico II, Napoli, Italy, July 14.

System Identification: Nonlinear Model Identification, Dipartimento di Informatica e Sistemistica, Universita degli Studi di Napoli Federico II, Napoli, Italy, July 14.

System Identification of Continuous-Time Models, Dipartimento di Informatica e Sistemistica, Politechnico di Milano, Milano, Italy, July 28.

System Identification: Development of Process Knowledge via Measurement, Data Analysis and Mathematical Models, Nutek Workshop on Multivariate Statistics and Chemometrics, Lund University, Lund, September 6.

Classification of Electrocardiographic P-wave Morphology, IEEE Conf. Decision and Control (CDC 2000), Invited lecture, Sydney, Australia, December 14.

Covariance analysis, positivity and the Yakubovich-Kalman-Popov Lemma, (CDC 2000), Sydney, Australia, Decenber 14.

Lincoln, Bo

Optimal Control over Networks with Long Random Delays, International Symposium on Mathematical Theory of Networks and Systems, Perpignan, France, June 20.

Efficient Pruning of Search Trees in LQR Control of Switched Linear Systems, Conference on Decision and Control, Sydney, Australia, December 13.

Möllerstedt, Erik

Stability Analysis Modern Electric Networks, Invited lecture at ABB Corporate Research, Baden-Dättwil, Switzerland, April 14.

Rantzer, Anders

Stability and Robustness Analysis of Nonlinear and Uncertain Systems, Invited lecture at the Mathematical Colloquium at Lund University, Lund, Sweden, March 15.

Analysis and Optimal Control of Hybrid Systems, Vrije Universiteit, Amsterdam, The Netherlands, April 3.

On Optimal Control of Hybrid Systems, Workshop on Hybrid Control and Automotive Applications, Lund, Sweden, May 6.

On Convexity in Stabilization of Nonlinear Systems, Plenary lecture, Second Nonlinear Control Network Workshop, Paris, France, June 8.

On the Dual of Lyapunov's Second Theorem, University of Minnesota, Minneapolis, USA, June 23.

On Convexity in Stabilization of Nonlinear Systems, University of Illinois, Urbana-Champaign, USA, June 26.

On the Dual of Lyapunov's Second Theorem, Invited lecture at American Control Conference, Chicago, USA, June 28.

On Convexity in Stabilization of Nonlinear Systems, Massachusetts Institute of Technology, Cambridge, USA, July 11.

On Stability and Convergence of Nonlinear Systems, Invited lecture at the Peetre Conference on Function Spaces, Interpolation Theory, and Related topics, Lund, Sweden, August 21.

A Dual View on Control with Constraints, Plenary lecture at Workshop on Systems with time-Domain Constraints, Eindhoven, the Netherlands, August 30.

On Convexity in Stabilization of Nonlinear Systems, Conference on Decision and Control, Sydney, Australia, December 14.

Sandberg, Henrik

Harmonic Modeling of the Motor Side of an Inverter Locomotive, CCA 2000, Anchorage, Alaska, September 27.

Harmonic Modeling of the Motor Side of an Inverter Locomotive, Institute of Systems Research, University of Maryland, USA, October 3.

Solyom, Stefan

ABS - A Piecewise Linear Approach, H2C Project Workshop, Daimler-Chrysler AG, Stuttgart, Germany, September 15.

Tummescheit, Hubertus

Modeling of Two-Phase Flows with Modelica, Seminar. 3rd MATHMOD Vienna, Viennea, Austria, February 3,

Physical System Modeling with Modelica: Tutorial and Overview, Seminar at Ford Motor Company, Dearborn, MI, USA, Feb 16.

Physical System Modeling with Modelica, Seminar at California Institute of Technology, Pasadena, CA, USA, March 25.

Introduction to Physical System Modeling with Modelica, Seminar at United Technologies Research Lab, Hartford, CO, USA, August 15.

Modeling of Fuel Cells with Modelica and the ThermoFlow Library, Seminar at International Fuel Cells, Hartford, CO, USA, August 18.

Object-Oriented Modeling of Physical Systems with Modelica, Short Course on Modeling with Modelica at Deparment of Energy Engineering, Copenhagen, Denmark, September 20 and September 27.

Development of a Modelica Base Library for Modeling of Thermo-Hydraulic Systems, Seminar. Modelica 2000 Workshop, Lund, Sweden. October 24.

Development of a Modelica Base Library for Modeling of Thermo-Hydraulic Systems, Seminar. Chemnitz-Hamburger Symposium, Hamburg, Germany. November 16.

Wallén, Anders

Tools for Autonomous Process Control, Seminar at AssiDomän, Piteå, Sweden. March 22.

Wittenmark, Björn

Interactive Simulation in Control Education, CITU, Lund University, Sweden, May 4.

Time Delays in Computer Networks for Control, Universidad Tecnica Federico Santa Maria, Valparaiso, Chile, October 13.

Input-output Pole-placement Design, Universidad Tecnica, Federico Santa Maria, Valparaiso, Chile, October 18.

The Servo problem and Integrators, Universidad Tecnica, Federico Santa Maria, Valparaiso, Chile, October 20.

Minimum Variance Control and LQG Design, Universidad Tecnica, Federico Santa Maria, Valparaiso, Chile, October 25.

Operators, Transforms, and Multirate Sampling, Universidad Tecnica, Federico Santa Maria, Valparaiso, Chile, October 27.

15. Seminars at the Department

Seminars presented in order of date. The seminars were given at the department during 2000, 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 10: **Hubertus Tummescheit** (AC), *Physical Modeling with Modelica.*

Jan 19: **Tommy Johansson** (LTH), *Precise Navigation for an Agricultural Robot.* MSc-thesis presentation.

Jan 21: **International Project Group** (LTH+EM Nantes), *Simulation and Control of a Plate Heat Exchanger.*

Jan 28: **Alfredo Loreto** (Universita degli Studi Di Roma 'La SAPIENZA'), *Real-Time Control over a Communication Network with Delays.* MSc-thesis presentation.

Feb 3: **Anna Klingberg** (LTH), *Modeling and Optimization of Batch Distillation.* MSc-thesis presentation.

Feb 11: **Niklas Petersson, Martin Santesson** (LTH), *Experimental slip based road condition estimation.* MSc-thesis presentation.

Feb 15: **Jonas Levin** (LTH), *Sequential Paging for Moving Mobile Users.* MSc-thesis presentation.

Feb 17: **Guy Dumont** (University of British Columbia), *Loop shaping controller design for a spatially distributed system.*

Feb 18: **Anders Wallén** (AC), *Tools for Autonomous Process Control.* Doctoral dissertation defence.

Feb 22: **Rickard Bondesson, Johan Gagner** (LTH), *Adaptive Control of Nonlinear Throttle Unit.* MSc-thesis presentation.

Feb 22: **Fredrik Hansson, Peter Davidsson** (LTH), *Communication between Matlab/Simulink and ABB Advant Control Builder.* MSc-thesis presentation.

Feb 23: **Alina Besancon-Voda** (LAG, France), *Approaches to Identification and Uncertainty Bounding based on LMI techniques.*

Feb 24: **Hélène Panagopoulos** (AC), *PID Control; Design, Extension, Application.* Doctoral dissertation defence.

Feb 29: **Rolf Johansson** (AC), *NUTEK-video: The Thinking Machine.*

March 16: **Krister Forsman** (ABB), *Diagnostics and performance assessments for process industrial control.*

March 27: **Michael Lundh** (ABB), *Presentation and demonstration of ABB's MPC controller.*

April 7: **Philippe de Wilde** (Imperial College, London), *Adaptation in a fuzzy environment (slides).*

May 2: **Deb Ghatak, Johan Olofsson** (LTH), *Design, Implementation and Verification using UML-RT in GSM Radio Base Station 2000.* MSc-thesis presentation.

May 19: **Dietmar Bauer** (TU Wien), *Analysis of the Larimore type of subspace methods.*

May 26: **Gerhard Fohler** (Mälardalen University) *From Determinism to Flexibility - Merging Time and Events.*

May 26: **Anton Cervin** (AC) *Towards the Integration of Control and Real-Time Scheduling Design.* Lic Tech dissertation seminar.

May 31: **Johan Hamberg** (FOA) *The Method of Controlled Lagrangians.*

June 9: **A. C. Antoulas** (Rice University) *An overview of model reduction methods for large-scale systems.*

June 13: **Raffaello D'Andrea** (Cornell University) *Robust and Optimal Control of Complex Interconnected Systems.*

June 13: **Luigi Palopoli** (Scuola Superiori di Pisa) *On the Application of Soft Real-time Techniques to Control Problems.*

June 14: **Henrik Olsson** (LTH) *Linear Neural Control Methods.* MSc-thesis presentation.

June 14: **Raffaello D'Andre** (Cornell University) *The Robo Files: Building the best robot soccer team in the world.*

June 15: **Carina Hansen, Cecilia Svensson** (LTH) *2D Inverted Pendulum Control.* MSc-thesis presentation.

June 15: **Jim Rawlings** (University of Wisconsin-Madison) *Disturbance models and robustness.*

June 15: **Jim Rawlings** (University of Wisconsin-Madison) *Overview talk. What is Model Predictive Control?.*

June 16: **Jim Rawlings** (University of Wisconsin-Madison) *Nonlinear models.*

June 16: **Jim Rawlings** (University of Wisconsin-Madison) *Targets and schedules.*

June 20: **Kuan Luen Ng** (Imperial College) *Darwinian Selection: On Evolving Programs and Solutions to Control Problems using Genetic Programming.* MSc-thesis presentation.

June 20: **Jim Rawlings** (University of Wisconsin-Madison) *State estimation and monitoring.*

July 14: **Franck Ruffier** (Institut National Polytechnique de Grenoble) *Control of a High Voltage Power Supply for a Traveling Wave Tube Transmitter.* MSc-thesis presentation.

Aug 21: **Geir Dullerud** (University of Illinois) *Distributed and LTV Control of Heterogeneous Systems.*

Sep 4: **Pablo Parrilo** (CalTech) *Semidefinite Programming and Semialgebraic Geometry in Robustness and Optimization.*

Sep 8: **John Doyle** (CalTech) *Web/internet traffic and complexity at the edge of nonsense.*

Sep 8: **John Doyle** (CalTech) *HOT theories of turbulence and statistical physics.*

Sep 13: **Johan Åkesson** (LTH) *Safe Manual Control of Unstable Systems.* MSc-thesis presentation.

Sep 27: **Luca Caputo** (Universita Degli Studi, Firenze) *Control of Energy Storage Device for Rail Vehicles.* MSc-thesis presentation.

Sep 27: **Martin Andersson** (LTH) *Implementering och tillämpningar av nya reglertrimningsmetoder.* MSc-thesis presentation.

Sep 28: **Per-Olof Gutman** (Technion – Israel Inst. of Technology) *QFT in the basic Single Input Single Output case.*

Sep 28: **Per-Olof Gutman** (Technion – Israel Inst. of Technology) *The robust control problem. Uncertain linear plants.*

Sep 29: **Per-Olof Gutman** (Technion – Israel Inst. of Technology) *Comparison between QFT and other robust control methods.*

Sep 29: **Per-Olof Gutman** (Technion – Israel Inst. of Technology) *QFT for non-minimum phase and computer controlled systems, Landau example.*

Oct 2: **Tomi Ervasti, Torkel Niklasson** (LTH) *SDL Programming of LEGO Robots.* MSc-thesis presentation. Oct 13: **Mathias Larsson** (LTH) *Modellering och simulering i Matlab för ABB's Control Builder.* MSc-thesis presentation.

Oct 19: **Henrik Gordon Petersen** (Odense University) *Robotics and Applied Software Engineering at Odense University.*

Nov 7: **Johan Brodin, Per Nilsson** (LTH) *Implementing a Wireless I/ O over Bluetooth.* MSc-thesis presentation.

Nov 9: **David J Hill** (University of Sydney, Australia) *Stability and Control within Electricity Markets.*

Nov 10: **Erik Möllerstedt** (AC) *Dynamic Analysis of Harmonics in Electrical Systems.* Doctoral dissertation defence.

Nov 13: **Wolfgang Reinelt** (Linköping University) *Design of saturation-avoiding controllers: a double Youla approach to deal with plant uncertainty.*

Nov 14: **Allessandro Pontremoli** (Universita Degli Studi Di Roma 'La SAPIENZA') *Modeling and Control of a Paper Drying Section using Modelica.* MSc-thesis presentation.

Nov 14: **Björn Nilsson** (LTH) *Modeling of Industrial Glass Fibre Production.* MSc-thesis presentation.

Nov 16: **Filip Lindau** (LTH) *Feedback control of plasma position in the EXTRAP-T2 fusion experiment.* MSc-thesis presentation.

Nov 16: **Jens Axelsson** (LTH) *Operate-IT – WMI Aspect.* MSc-thesis presentation.

Nov 21: **Sara Liljenborg, Anders Olsson** (LTH) *Force Control in Robotics.* MSc-thesis presentation.

Nov 24: **Dan Henriksson** (LTH) *Observer-based Impedance Control in Robotics.* MSc-thesis presentation.

Nov 28: **Michael Schinkel** (University of Glasgow) *Sample Data Control with Varying Sampling Time.*

Dec 7: **John Fredriksson, Andreas Rudolf** (LTH) *Probing control of glucose feeding in Saccharomyces cerevisiae cultivations.* MSc-thesis presentation.

Dec 20: **Peter Odebjer, Johan Svahn** (LTH) *Linearization and Non-linear Control in Flight-Control and Aeroelasticity for Civil Aircraft using MatrixX.* MSc-thesis presentation.