Activity Report: Automatic Control 2001

Johansson, Rolf; Tuszynski, Agneta

2002

Activity Report

Automatic Control

2001

LUND INSTITUTE OF TECHNOLOGY
Lund University

Mailing address
Department of Automatic Control
Lund Institute of Technology
Box 118
SE–221 00 LUND SWEDEN

Visiting address
Institutionen för Reglerteknik
Lunds Tekniska Högskola
Ole Römers väg 1, Lund

Telephone
Nat 046–222 87 80
Int +46 46 222 87 80

Fax
Nat 046–13 81 18
Int +46 46 13 81 18

Generic email address
control@control.lth.se

WWW and Anonymous FTP
http://www.control.lth.se
ftp://ftp.control.lth.se/pub

The report was edited by Agneta Tuszyński and Rolf Johansson

Printed in Sweden
Universitetstryckeriet, Lund, May 2002

ISSN 0280–5316
ISRN LUTFD2/TFRT--4029--SE

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, 2001.

The budget for 2001 was 24 MSEK. The proportion coming from the University was 51%.

Two PhD theses were defended this year, by Jonas Eborn and Mattias Grundelius. This brings the total number of PhDs graduating from our department to 62. A Lic Tech thesis was completed by Johan Bengtsson. 4 new PhD students have been admitted during the year: Ola Slätteke, Jacob Svendenius, Johan Åkesson, and Tomas Olsson. Bo Bernhardsson, one of our professors, is on temporary leave and started to work for Ericsson Mobile Communications AB, Lund and 3 persons with doctor's degree left the department: Erik Möllerstedt started to work for DECUMA AB in Lund, Jonas Eborn for United Technology Research Center in Hartford, CT in USA, and finally Mattias Grundelius started to work for TAC AB in Malmö.

In the civilingenjör (master) program we have 10 courses. The total number of students who finished the courses were 623, and 28 students completed their master theses. The total teaching effort corresponds to 96 full-year equivalents.

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

Today the department has seven professors and one professor emeritus.

A workshop entitled "NACO2 Automotive Control Workshop" was organized by the Department of Automatic Control at LTH and supported by the EU/RTN network NACO2 – Nonlinear and Adaptive Control. The purpose of the meeting was to bring together leading scientists to discuss state of the art theory and applications of automotive control. The topics included

- ABS
- Active Suspension
- Combustion Engine Control
- Cruise Control & Automated Highway
- Drive Line and Transmission

During March 8–9 the department hosted the ARTES Graduate Student Conference 2001. The number of participants was 42. A plenary on the Anoto technology was held by Pelter Ericsson, Anoto AB.

The department participate in 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 VINNOVA, Swedish industry, and Lund University.

Our retrospect this year, Chapter 7, describes our research in Adaptive Dual Control since 1960.

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

	97	98	99	00	01	Sum
Books	2	1	2	0	0	5
Papers	15	24	24	18	16	97
Conference papers	45	37	45	37	20	184
PhD theses	1	2	7	3	2	15
Licentiate theses	3	6	1	1	1	12
Master theses	18	20	25	24	23	110
Internal reports	11	11	8	5	5	40

Acknowledgments

We want to thank our sponsors, The Swedish Agency for Innovation Systems (VINNOVA), The Swedish Research Council (VR), The European Council, Foundation for Strategic Research (SSF), The Swedish Foundation for International Cooperation in Research and Higher Education (STINT), ABB Automation Technology Products AB, Active Biotech, Lund Research Center AB, Biovitrum AB, BlueCell, Connect-Blue, C-Technology, Ericsson Microwave, Ericsson Mobile Communications AB, Haldex Brake Products AB, Hörjel Foundation, IAR Systems, Knut and Alice Wallenberg Foundation, LM Ericsson Foundation, LU Kompetensutvecklingsfond, Pharmacia AB, Q-labs, SBL Vaccine AB, Sony Ericsson Mobile, Sydkraft AB, Swedish Medical Research Council (MFR), TAC, Telelogic, Tetra Pak Research & Development AB, The Royal Physiographic Society, and Volvo Technical 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.

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
```

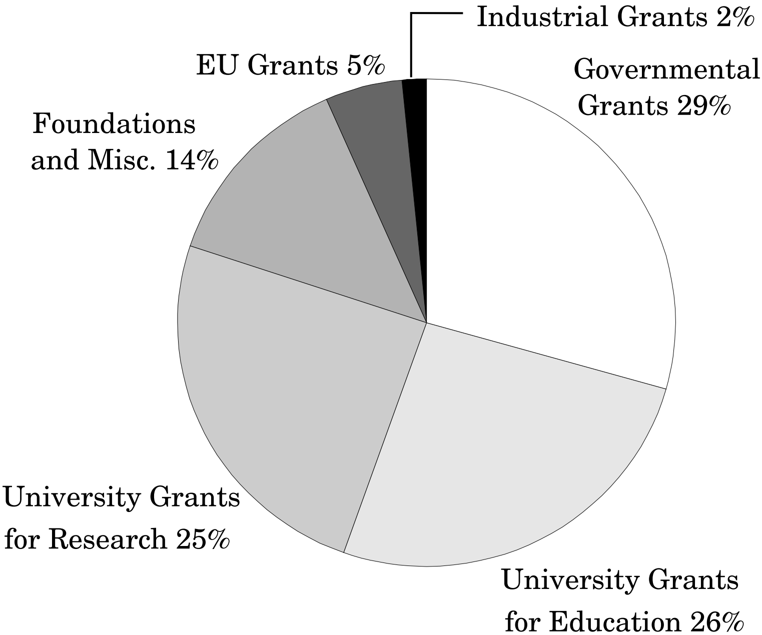
Our web page `http://www.control.lth.se/people/telemail.html` contains a complete list of email addresses. The department also has a generic email address:

`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 2001 was 24 MSEK. The income comes from Lund University (51%) 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 2001 we had the following contracts:

- VR – Control of Industrial Processes (block grant)
- VR – Industrial Aspects of on-line Monitoring and Diagnosis
- VR(NFR) – Theory for Modeling, Control and Analysis of Periodic Systems
- VINNOVA – Modeling and Simulation of Complex Systems
- VINNOVA – Data Integration and Force Control for Robots
- VINNOVA – Automatic Control and Driver Model
- VINNOVA – Process Control for Cultivation of Micro Organisms
- VINNOVA – Distributed Control of Safety Critical Systems
- VINNOVA – Basic Control Functions for the Process Industry
- VINNOVA – Lund Center for Applied Software Research (LUCAS)
- STINT – Funding for research collaboration with Caltech
- SBL Vaccine 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
- Pharmacia AB – Control of Genetically engineered *E. coli*.
- EU ESPRIT LTR – Heterogeneous Hybrid Control (H2C)
- EU/GROWTH – Advanced Decision Systems for the Chemical/Petrochemical Manufacturing Industries (CHEM)
- EU HPRN-CT - Nonlinear and adaptive control (NACO2)
- EU IST 2000 – Competitive and Substainable Growth (CHEM)

The block grant from VR and the CPDC grant from SSF are long range and some of the VINNOVA 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 Ultra10 or better. Many also have laptop computers running either Windows or Linux. 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.

During the year JGrafchart, a Java-based graphical editor and run-time system for Grafcet/Sequential Function Chart style sequential logic control has been introduced in our sequence control laboratories.

Throttle servo

The throttle servo process, which was built during 2001 at the Department, contain the same throttle unit from Volvo which is used for controlling the airflow to the engines in most of their new car models since 1999.

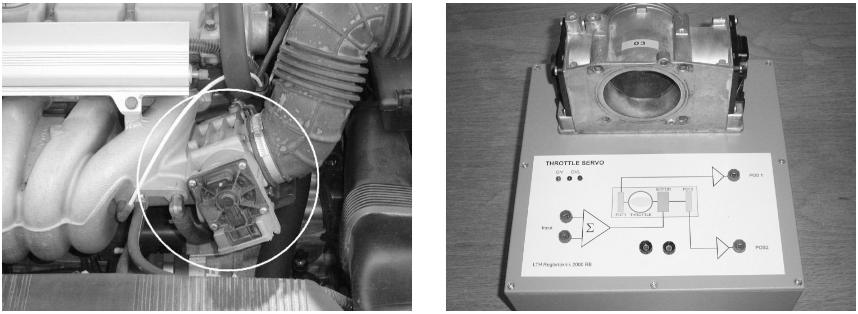


Figure 3.1 *(Left)* The throttle in a Volvo V70 (99). *(Right)* The lab process.

The throttle process is used in a laboratory exercise of the course *Nonlinear Control and Servo Systems* to illustrate dead-zone compensation. In addition to the dead-zone, the characteristics and dynamics of the throttle significantly change for different operating regions. The throttle servo is also used in student projects of the *System Identification* course and has been the topic of a couple of master thesis projects, for which the first prototype was built.

The drive electronics in the lab process has been totally redesigned for our own purposes. The throttle servo motor is driven by a switched DC amplifier from Elmo Motion Control SSA12/40. It is configured for driving 12V/4A continuously (peak 6A). The input range for the process is ±10V, where 1 V corresponds to 0.6 A current generated from the servo amplifier driving the servo. The output signal is proportional to the throttle angle (output range ±10V), where the two original potentiometers for measuring the throttle angle are used.

Robotics Laboratory

The Robotics Laboratory, containing three 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 2000"), serves as a 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.

4. Education

Engineering Program

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

Automatic control courses are taught as part of the engineering curricula in Engineering Physics (F), Electrical Engineering (E), Computer Engineering (D), Mechanical Engineering (M), Industrial Management and Engineering (I), Chemical Engineering (K) and Environmental Engineering (W). Our courses are listed in Table 4.1.

During 2001, 623 students passed our courses and 28 students completed their master-thesis projects. The number of registered students corresponded to 96 full-year equivalents during the year. The numbers for 2000 were 721, 32, and 112 respectively.

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

Information on WWW

Many students have access to Internet via Lund University. Therefore we have made a great effort to present the education on web pages. Each course in the engineering program has its own 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)	314
Reglerteknik AK–M *FRT061* (Automatic Control, basic course)	132
Processreglering (K) *FRT080* (Automatic Process Control)	27
Digital Reglering (FED) *FRT020* (Computer-Controlled Systems)	21
Realtidssystem (FED) *FRT031* (Real-Time Systems)	55
Systemidentifiering (FED) *FRT041* (System Identification)	12
Adaptiv reglering (FED) *FRT050* (Adaptive Control)	15
Olinjär reglering och Servosystem (M) *FRT075* (Nonlinear Control and Servo Systems)	13
Internationell projektkurs i reglerteknik *FRT100* (International Project Course in Automatic Control)	11
Systemteknik (W) *FRT110* (Systems Engineering)	25
Examensarbete 20 poäng *FRT820* (Master-thesis project, 5 months)	28

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

Doctorate Program

Two PhD theses were defended by Jonas Eborn and Mattias Grundelius. This brings the total number of PhDs graduating from our department to 62. A Lic Tech thesis was completed by Johan Bengtsson. Abstracts of the theses are given in Chapter 8.

We have admitted four new PhD students during the year: Ola Slätteke, Jacob Svendenius, Johan Åkesson and Tomas Olsson.

The following PhD courses were given:

- Linear Systems I (A. Gulchak) 5 points
- Case Studies in Control (T. Hägglund) 3 points
- Nonlinear and Uncertain Systems (A. Rantzer) 2 points
- Control Laboratory (K. E. Årzén) 5 points
- Synthesis (B. Bernhardsson and P. Hagander) 4 points
- Geometric Control and Mechanics (Naomi Leonard) 5 points
- Physical Modeling and Dynamic Systems (J. Eborn) 4 points
- Languages for Automation (K.E. Årzén) 3 points
- BlueTooth in Industry (K.E. Årzén) 1 point
- Optimization by Vector Space Methods (A. Gulchak and A. Rantzer) 5 points

5. Research

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

The major research areas are:

- Nonlinear and Uncertain Systems
- Modeling and Simulation
- Process Control
- Biotechnology Processes
- Robotics
- Real-Time Control
- Biomedical Systems
- Automotive Systems

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

Nonlinear and Uncertain Systems

Control of Nonlinear and Uncertain Systems

Researchers: Anders Rantzer, Bo Bernhardsson, and Andrey Gulchak

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

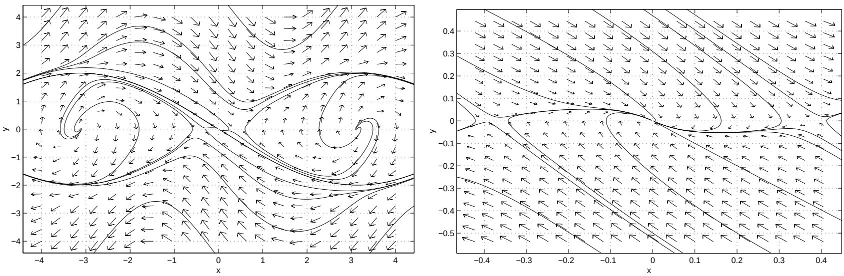


Figure 5.1 Left: Phase plot for smooth pendulum swing-up control. Right: Magnified phase plot near upright equilibrium.

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

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

For several years, we have been developing the analysis framework based on integral quadratic constraints. This work is done in cooperation 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 Gulchak 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 impossible to satisfy.

Hybrid Control

Researchers: Bo Bernhardsson, Sven Hedlund, Bo Lincoln, Stefan Solyom, and Anders Rantzer

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

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

We have recently initiated a very exciting development based on approximations of the cost function. It turns out that the exponential complexity of traditional dynamic programming algorithms often can be drastically reduced by relaxing the demand for optimality. In fact, finding a solution which is guaranteed to be within 10% from the optimum can be much less expensive than finding one within 1%. Figure 5.2 illustrates an example where the cost to go is computed backwards in time, starting at $T = 200$. Notice that the size of the search tree first grows exponentially for time steps down to about $T = 180$, then the size starts to shrink and finally stabilizes at a lower level that depends on the requested optimization accuracy.

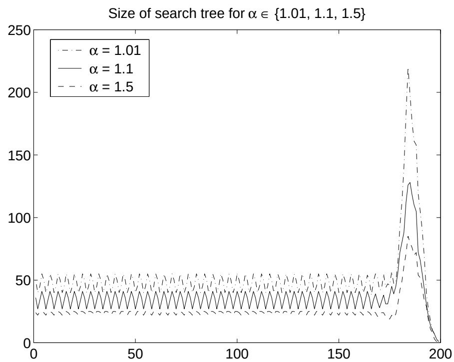


Figure 5.2 Size of the search tree as a function of time. The first step is at 200, as the tree is expanded backwards. The tree size first grows exponentially for time steps down to about 180, then the size starts to shrink and finally stabilizes at a lower level.

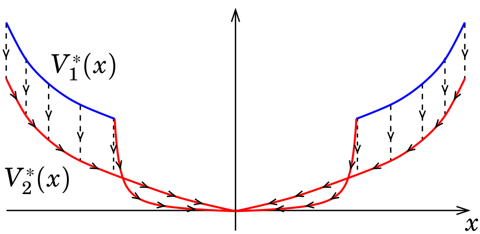


Figure 5.3 Optimal cost functions for a simple hybrid control problem. A vehicle should be brought to desired position and velocity using gear shifts (discrete) and throttle adjustment (continuous). A unit cost is assigned to each gear shift. The two curves correspond to the two possible initial gears.

Modeling and Simulation

Extremal Control of Wiener Processes

Researchers: Björn Wittenmark in cooperation with Robin J, Evans, Dept. of Electrical and Electronic Engineering, University of Melbourne, Australia

In this project we investigate different approaches to extremal control. Especially, processes of Wiener type are considered. These models consists of a linear part followed by a nonlinearity. In the project nonlinearities having one extremum point are considered. The purpose of the control is to keep the output of the process as close as possible to the extremum point. Different control schemes are discussed and analyzed. The main problem in the control of this kind of Wiener model processes is the non-uniqueness of the inverse of the nonlinearity. This causes problems, for instance, in the estimation of the states of the process and the identification in the adaptive case.

Modeling and Simulation of Complex Systems

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

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. The design of Modelica Version 1.0 was finished in September 1997. Since 2000, the non-profit Modelica Association has taken over the responsibility of the further development of the Modelica language. In February 2002, Version 2.0 has been released and the commercial simulation tools Dymola and MathModelica support Modelica. 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, ThermoFluid. The base library contains models for lumped or discretized control volumes, based on the physical balance equations of mass, energy and momentum. The ThermoFluid library is designed to be flexible, using Modelica class parameters to exchange medium property descriptions and machine dependent characteristics. In the library, particular attention has been given to efficient dynamic simulation involving physical property calculations, since these are usually designed for static calculations. The ThermoFluid library is now used in a variety of industrial projects for the modeling of fuel cells, micro turbine systems, steam distribution nets and refrigeration systems.

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.

Reduction and aggregation of process models

Researchers: Henrik Sandberg and Anders Rantzer

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

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

This is one reason why there is a strong need for methods and tools that can take a complex model and deduce simple models for various purposes such as control design. A more general reason is that simplified models are useful to point out the basic properties of a system and can provide good insight.

Our approach to model simplification has so far been based on linearization about trajectories. This results in time-varying linear models which can capture many effects not seen in linear time-invariant modeling, such as frequency coupling.

During 2001 the work has been focused on generalizing the well-known theory for balanced truncation of time-invariant linear models into the time-varying framework. Figure 5.4 shows simulations of reduced models for a non-linear hydrogen-oxygen reaction.

System Identification

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

An identification algorithm that effectively fits continuous-time transfer functions and finite-bandwidth noise models to data has been published. Analysis of this class of algorithms proves convergence properties similar to that of maximum-likelihood identification of 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.

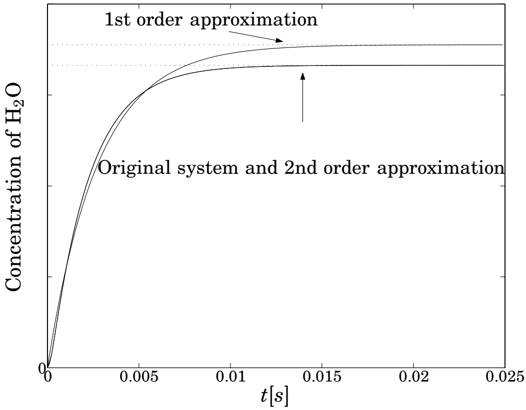


Figure 5.4 A step response of a 8th order non-linear hydrogen-oxygen reaction together with 1st and 2nd order approximations. A 2nd order model is enough to capture the system dynamics.

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.

Process Control

Center for Chemical Process Design and Control (CPDC)

Researchers: Karl-Erik Årzén, Tore Hägglund, Ari Ingimundarsson, Rasmus Olsson, Anders Rantzer, Henrik Sandberg, Ola Slätteke, Björn Wittenmark

The Center for Chemical Process Design and Control (CPDC) is sponsored by the Swedish Foundation for Strategic Research (SSF) and is a cooperation between about ten departments at Chalmers University of Technology, Lund Institute of Technology, and Royal Institute of Technology. The program is administrated from Department of Automatic Control, LTH. New program director for the program is Bernt Nilsson, Chemical Engineering 1, LTH.

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

The projects supported by the CPDC program are:

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

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 practice 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 year the focus has been on comparing the performance of PID controllers and dead-time compensators. The reason for this is that books about process control often lack recommendation about when to use dead-time compensators. In light of a renewed interest indead-time compensators that has been noticed in the literature lately, an attempt has been made to investigate when it is appropriate to use dead-time compensators in stead of the most common control structure in process control, namely the PID controller.

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

Performance Monitoring of Control Loops
Researchers: Ari Ingimundarson and Tore Hägglund

The need to monitor the performance of controllers in the process industry has been widely recognized. The research activities in this project has been focused on a new method which uses a synthetic gradient of a quadratic cost function to draw conclusions about performance. Effectively the method works by analyzing the frequency content of the disturbances affecting the control loop with regard to controller parameters. The research is on an early stage with many questions to be answered.

The project is supported by the CPDC program.

Advanced Decision Support Systems for the Chemical/Petrochemical Manufacturing Industries (CHEM)
Researchers: Karl-Erik Årzén, Johan Åkesson, Rasmus Olsson

The aim of the EU/GROWTH project CHEM (http://www.chem-dss.org) is to develop an integrated set of toolboxes for various operator support functions in the process industries. CHEM started April 1, 2001 and will last for three years. The partners within CHEM are: Institut Francais de Petrol, France (Coordinator), Corus (ex. British Steel), UK, Computas, Norway, Gensym, France, KCL, Finland, LAAS, Toulouse, France, LAG, Grenoble, France, Lund University, Metso Automation, Finland, Thales (ex Thomson), France, Universitat Politecnica de Catalunya, Spain, Université des Sciences et Technologies de

Lille (LAIL), France, Universitat de Girona, Spain, UPM Kymmene, Finland, VTT Automation, Finland, Warsaw University of Technology, Poland, and ZAP, Poland.

The Department of Automatic Control is responsible for the development of an operator procedure handling toolbox that will be used to support the operators in process state transitions. The toolbox is based on Grafchart, a G2 based toolbox for supervisory level sequence and procedure handling, and JGrafchart, a new Java-based version of Grafchart. The department is also investigating the possibility to use numerical optimization techniques for grade change sequence generation. So far, an MPC approach has been used.

In the beginning of 2001 a decision was made to change implementation platform for the work on Grafchart from G2 from Gensym Corporation to Java. The new version is called JGrafchart. JGrafchart currently supports the following features:

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

JGrafchart is implemented in Java 1.3 and Swing. The following external software components are used:

- The JGo graphical object editor class package from Northwoods Corp.
- The JavaCC parser generator.
- Sun's XMLÖ parsers for Java.
- The xmlBlaster message-oriented publish and subscribe middleware.

Control and diagnosis in batch processes

Researchers: Rasmus Olsson and Karl-Erik Årzén

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

The work in the first part of the project is a continuation of the work on recipe-based batch processes by Charlotta Johnsson. The work is based on 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 2001 a collaboration has been started with Prof. Puigjaner's group at UPC in Barcelona. Our results will be applied to the PROCEL batch laboratory process at UPC. Our approach will be integrated with the reactive batch scheduling software developed at UPC. Part of this work is financed by the CHEM EU project.

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: Ola Slätteke, ABB and LTH, Björn Wittenmark, and Tore Hägglund, in cooperation with Krister Forsman, ABB Process Industries

The paper making process is essentially a very large drainage process. Consistency of the stock flow entering the paper machine head box is typically around 0.2% - 1.0% (2–10 g fiber per kg water). Although the drying section is only responsible for removing less than 1% of this water content, this is the part of the paper machine that, by far, consumes most energy. It is also in the drying section where most paper web strength forms and web shrinkage occurs and the part where the actual moisture control is performed. These are some of the reasons why this part of the paper machine is critical for the final paper qualities.

A dryer section in a paper machine can consist of up to one hundred steam heated cylinders and the length of the drying section can be above 100 meters. The cylinders are divided in 5 – 10 steam groups. The control of the steam pressure in these cylinder groups is in cascade control with the moisture control loop. This project is focused on the modeling and control tuning of this process. From mathematical model

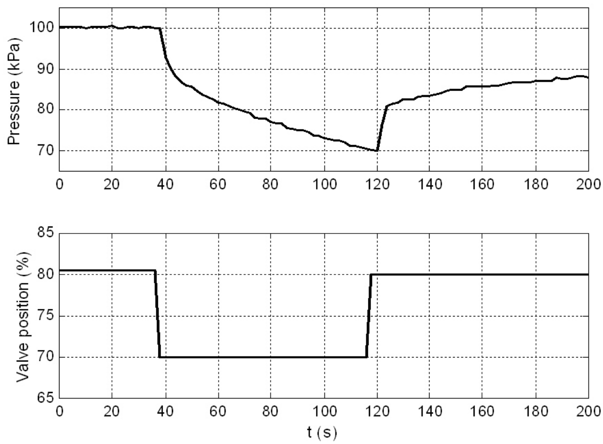


Figure 5.5 Open loop step response of the steam pressure in a cylinder group of a paper machine. This can be modelled as a second order process, the so called IPZ model.

building and experiments on industrial paper machines it is found that the dynamics from the steam valves to the steam pressure in the cylinders can be described by a simple process model, the so called IPZ model. See Figure 5.5. This model has an integrator, one pole, and one zero. The dynamics from the steam pressure to the moisture in the paper can be described by a first order model plus dead time, where the dead time is the dominating part.

Basic Process Control Functions

Researchers: Tore Hägglund, Ari Ingimundarson, and Hélène Panagopoulos

This project has been 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.

Deadtime-compensating controllers with automatic tuning procedures have been developed within the project, as well as filters for active control of undamped modes.

A new ratio control structure, the Blend Station, that manages to keep the ratio even during transients, has also been developed within the project. The Blend Station is patented. During this year, the Blend Station has been implemented in industrial DCS systems, and field tests are initiated.

PID Control

Researchers: Karl Johan Åström and Tore Hägglund

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

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

During the last year, these design methods have been used to develop simple tuning rules that are based on simple process models obtained from a step response experiment. By determining the static gain, the apparent time constant, and the apparent dead time of the process, simple tuning rules that provide controller parameters that differ less than 15% from the optimal ones have been derived.

Control Loop Structure Assessment

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

The work is focused on assessing the control loop structure based on available measurements. The scenario studied consists of a SISO control loop that contains an additional exogenous signal. The aim is to develop methods that automatically decides whether or not the additional signal affects the control performance, in which way it affects the control loop, if it is possible to compensate for the exogenous signal by using, for example, feedforward, gain-scheduling or cascade control,

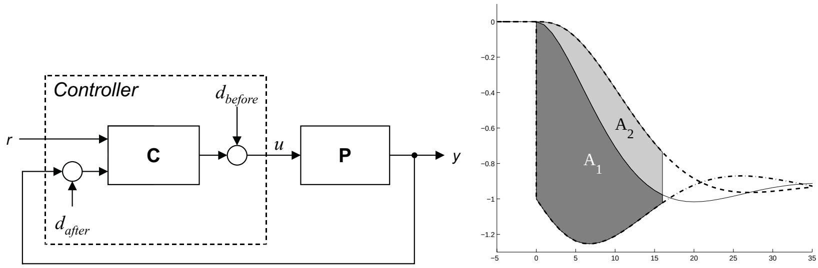


Figure 5.6 The feedforward index is based on comparison of control signals. The controller's response to the disturbance (solid), is compared to two references; the after-reference (dash-dotted), and the before-reference (dashed). The block diagram shows how the references can be generated by introducing a measured disturbance as a bias to the process value and the manipulated variable. The feedforward index is the ratio between the area A_1 and the reference area, $A_1 + A_2$.

and finally it would be desirable to estimate how much performance that can be gained by the compensation.

During 2001, the work focused on both feedforward control, with a patent pending, and cascade control. A feasibility study was done by implementing some of the ideas in Java, and now a test implementation is done in ABB's new control system Control^{IT}.

This project is funded by TFR/SSF in cooperation with ABB Automation Technology Products, and consists of an industrial PhD-student position for Mikael Petersson.

Biotechnology

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 analyzed for stability.

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

The strategy is now implemented at the Departments of Biotechnology and Chemical Engineering, Lund University, at Active Biotech, in Lund and at SBL Vaccin, Stockholm, at Pharmacia AB, Stockholm and Strängnäs, and tested with different E. coli strains and operating conditions. Good cultivation conditions and high production levels could be obtained from the first experiment. The strategy is also tested with good results in production scale and for other organisms like bakers yeast and cholera bacteria.

The work is funded by Vinnova, “Bioprocesser i industrin”, together with Pharmacia AB and SBL Vaccin.

Robotics

Robotics Research and Nonlinear Systems Research

Researchers: Rolf Johansson, Klas Nilsson, and Anders Robertsson

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

Another project is on the structure and programming of control systems for industrial robots. The problem addressed is how the software architecture and the real-time structure of a robot control system should be designed to allow easy and flexible incorporation of additional sensors and new control algorithms. A software layer between a supervisory sequence control layer and the basic control level has been proposed. Case studies and prototype experiments show promising results and further implementation is going on. A

NUTEK-sponsored research program Lund Research Programme in Autonomous Robotics with cooperation partners from Dept Production and Materials Engineering and Dept Industrial Electrical Engineering and Automation and industrial partners was continued during the year.

Real-Time Control

Distributed Control of Safety Critical Mechanical Systems

Researchers: 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 DICOSMOS2 project (Distributed Control of Safety Critical Mechanical Systems) supported by NUTEK/VINNOVA. This is a cooperation between Department of Computer Engineering, Chalmers, Department of Machine Design, KTH, Volvo Technological Development (VTD), and Department of Automatic Control. DICOSMOS2 started in 1999 and runs until the end of 2001.

As a means to combine methods and theory from automatic control, computer engineering, and mechatronics in the field of distributed safety-critical control systems, a case-study has been initiated in cooperation with Volvo Technological Development (VTD). The subject of the study is an electrical braking system with integrated anti-lock and yaw-control functionality for heavy duty tractor-semitrailer 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 as a first step. During 2000 a 3-DOF simulation model of the vehicle was constructed. A proposal on a

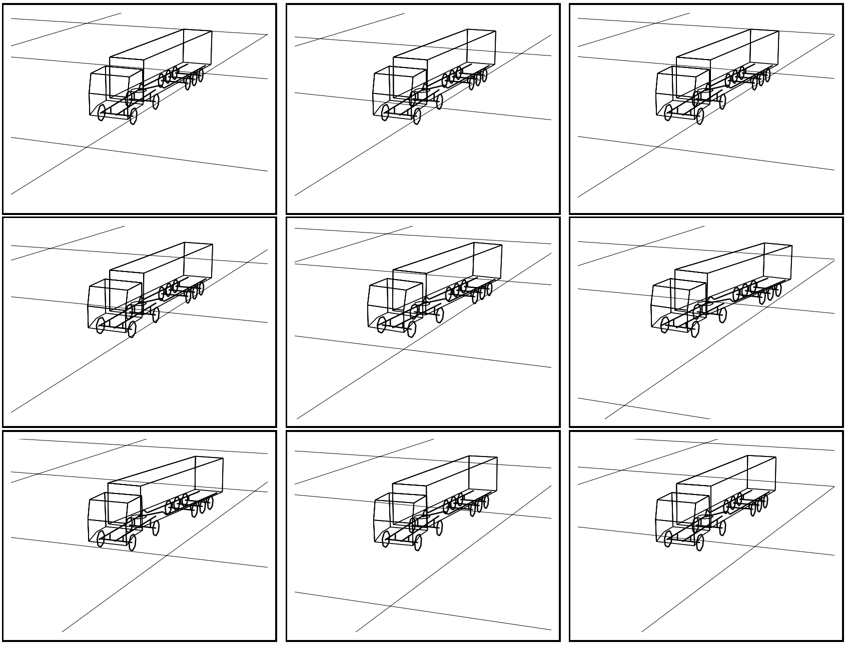


Figure 5.7 The 9-DOF tractor-semitrailer model is implemented in Matlab/Simulink. A tool for 3D-animations of simulation results is part of the implementation. The sequence above shows a lane-change maneuver at 80 km/h with 2.5 deg maximum wheel-angle. The wheel-angle input is obtained from recordings of a real driving experiment

system architecture based on dependability analysis was also produced. In 2001 a more complete 9-DOF model of the tractor-semitrailer was derived. This model describes handling dynamics more accurately, and may also find applications in hardware-in-the-loop simulations. Different yaw-control strategies based on LQ design were investigated. Figure 5.7 shows a simulation of a lane change.

A study was initiated on the influence on closed-loop control performance of transient hardware faults in CPUs executing control algorithms. A final report for DICOSMOS2 was delivered to VINNOVA.

Four graduate students were active in the case study: Magnus Gäfvert (Department of Automatic Control), Vilgot Claesson (Department of Computer Engineering, Chalmers), Martin Sanfridsson (Mechatronics Lab, KTH), and Örjan Askerdal (Department of Computer Engineering, Chalmers). The work during 2001 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.

Center for Applied Software Research (LUCAS)

Researchers: Karl-Erik Årzén, Rolf Johansson, Anders Robertsson, Anton Cervin, Dan Henriksson, 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 Platforms, Sony Ericsson Mobile, and ABB Automation Technology Products are gold members. Silver members are Q-Labs, Telelogic, and Ericsson Microwave, and the bronze members are TAC, connectBlue, BlueCell, IAR Systems, ABB Robotics, and C-Technology.

During the year two combined PhD courses and industrial seminar series have been given on Programming Languages for Automation and Bluetooth in Industry. The LUCAS Software Architecture Academy has also been started. This workshop activity aimed at gold and silver members will train the existing and new software architects in the participating companies.

Integrated Control and Scheduling

Researchers: Anton Cervin, Dan Henriksson, Anders Blomdell, Bo Lincoln and Karl-Erik Årzén, in cooperation with Teleca and DDA Consulting

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 Teleca and DDA Consulting. The project finances two ARTES PhD students, Anton Cervin at Automatic Control, and Sven Gestegård Robertz at Computer Science. The PhD student Dan Henriksson is also contributing to the project.

During 2001, the development of the MATLAB/Simulink-based real-time control systems simulator `TrueTime` was continued. `TrueTime` allows co-simulation of continuous process dynamics and multi-tasking real-time kernels and communication networks. The new version of the simulator is event-based, written in C, and allows the user tasks to be defined as M functions, C functions, or Simulink diagrams.

A MATLAB-based analysis tool called `Jitterbug` was also developed during the year. `Jitterbug` allows evaluation of a quadratic performance criterion for a control loop under various timing conditions. The tool is quite general and can be used to investigate the effect of jitter, delay, aborted computations, etc., on control performance.

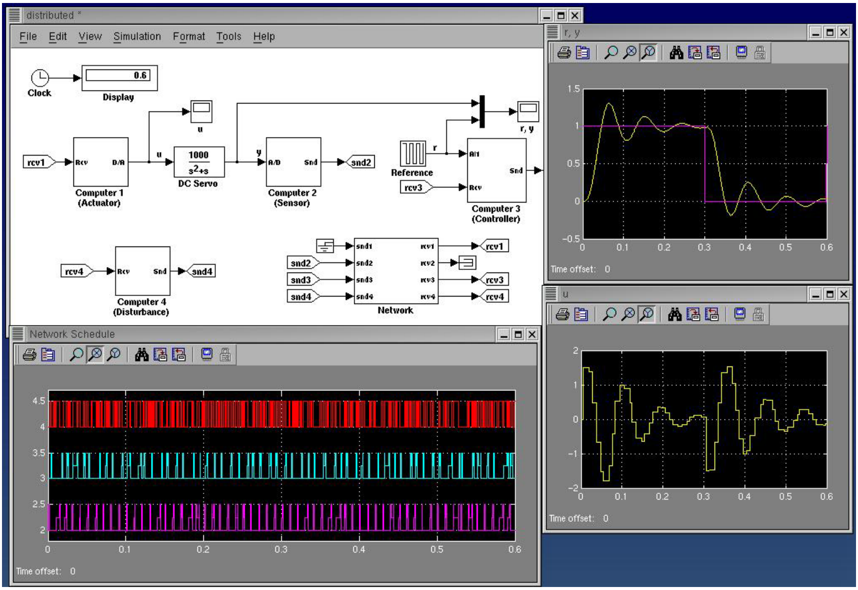


Figure 5.8 Screenshot of the `TrueTime` simulator.

The work on feedback scheduling has also continued. We have started to work on feedback scheduling of Model Predictive Controllers (MPC). These controllers are difficult to schedule using traditional real-time methods, since they can exhibit very large variation in execution time. During the year Anton Cervin has spent one month in Prof. Edward Lee's group at University of California, Berkeley.

Networked Control Systems

Researchers: Bo Lincoln, Anders Blomdell, Anton Cervin, Dan Henriksson, 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 is Bluetooth.

Biomedical Systems

Biomedical Modeling and Control

Researchers: Rolf Johansson in cooperation with Dr Måns Magnusson and Per-Anders Fransson, M.Sc. (Department of Oto-Rhino-Laryngology, Lund University Hospital)

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

Cardiologic Analysis and Modeling

Researchers: Rolf Johansson in cooperation with Prof. S. Bertil Olsson, and Jonas Carlson, M.Sc. (Dept. Cardiology, Lund University Hospital)

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

Automotive Systems

Control of Antilock Braking Systems

Researchers: Stefan Solyom and Anders Rantzer

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

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

Within this project, we have developed a gain scheduled PI controller, based on tire-slip value, velocity over ground and the maximum friction coefficient (i.e. friction coefficient at the top of the friction curve). This enables the controller to adapt to various fast changing road conditions. The main idea behind the slip control design has been to schedule the switching between a few sets of control parameters that locally, robustly stabilize the system for different slopes of the friction curve and which tolerate the time variations due to the decreasing velocity over ground of the car. Switching between the control parameters is done according to the estimated friction and slip, which define the operating point on the friction curve.

Tests have been carried out in a Mercedes E220 vehicle (Figure 5.9), provided by DaimlerChrysler, equipped with electro-mechanical brakes and brake-by-wire system.

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

Figure 5.9 Test vehicle for the H2C project

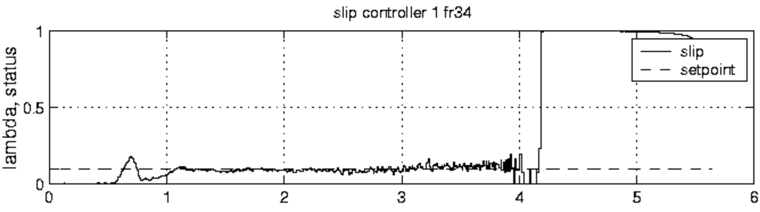


Figure 5.10 Test result for an emergency braking on dry asphalt. The longitudinal tire slip is depicted while braking from an initial velocity of $30m/s$ until standstill is achieved.

Adaptive Cruise Control and Driver Models

Researchers: Rolf Johansson, 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.

Electrically Actuated Brake System for Heavy Vehicles

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

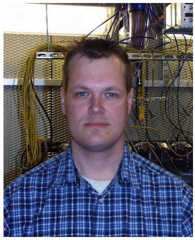
The project investigates the use of electrical power in control and actuation of brake system for heavy vehicles. The main issues are to determine how to make use of the advantages and what the needs of adjustments on the system this change will require. Using electrical brakes will result in a faster and more controllable system. Benefits from this are better performance for braking related functions, for example, anti lock-braking system. It will also introduce new needs of adjustment and safety thinking. The brake system is one of the most critical systems in the vehicle and new and different disturbances that can risk the safety will occur.

Estimation of the In-Cylinder Air/Fuel Ratio of an Internal Combustion Engine

Researchers: Rolf Johansson in cooperation with Prof Gunnar Lundholm, Per Tunestål, Div. Combustion Engines, Prof. Karl Hedrick, Dept Mechanical Engineering, UC Berkeley.

On April 6, 2001, Per Tunestål defended his doctoral thesis Estimation of the In-Cylinder Air/Fuel Ratio of an Internal Combustion Engine by the Use of Pressure Sensors, Div. Combustion Engines, Dept. Heat and Power Engineering, Mechanical Engineering, Lund University. The thesis was co-supervised by Prof. Karl Hedrick, UC Berkeley, Prof.

Gunnar Lundholm and Rolf Johansson. Opponent was Prof. Anna Stefanopoulou, University of Michigan, Ann Arbor MI.



This thesis investigates the use of cylinder pressure measurements for estimation of the in-cylinder air/fuel ratio in a spark ignited internal combustion engine.

An estimation model which uses the net heat release profile for estimating the cylinder air/fuel ratio of a spark ignition engine is developed. The net heat release profile is computed from the cylinder pressure trace and quantifies the conversion of chemical energy of the reactants in the charge into thermal energy. The net heat release profile does not take heat- or mass transfer into account. Cycle-averaged air/fuel ratio estimates over a range of engine speeds and loads show an RMS error of 4.1% compared to measurements in the exhaust.

A thermo-chemical model of the combustion process in an internal combustion engine is developed. It uses a simple chemical combustion reaction, polynomial fits of internal energy as function of temperature, and the first law of thermodynamics to derive a relationship between measured cylinder pressure and the progress of the combustion process. Simplifying assumptions are made to arrive at an equation which relates the net heat release to the cylinder pressure.

Two methods for estimating the sensor offset of a cylinder pressure transducer are developed. Both methods fit the pressure data during the pre-combustion phase of the compression stroke to a polytropic curve. The first method assumes a known polytropic exponent, and the other estimates the polytropic exponent. The first method results in a linear least-squares problem, and the second method results in a nonlinear least-squares problem. The nonlinear least-squares problem is solved by separating out the nonlinear dependence and solving the single-variable minimization problem. For this, a finite difference Newton method is derived. Using this method, the cost of solving the nonlinear least-squares problem is only slightly higher than solving the linear least-squares problem. Both methods show good statistical behavior. Estimation error variances are inversely proportional to the number of pressure samples used for the estimation as predicted by the central limit theorem.

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 Technology Products,
ABB Corporate Research,
ABB Industries,
ABB Robotic Products,
Biovitrum AB,
BlueCell,
Computas,
ConnectBlue,
Corus,
C-Technology,
DaimlerChrysler,
DDA Consulting
Dynasim AB,
Ericsson Microwave,
Ericsson Mobile Communications,
Gensym Corp.,
Haldex Brake Products AB,
IAR Systems,
IFP,
Pharmacia AB,
Q-labs,
SBL Vaccine AB,
SINTEF,
Sony Ericsson Mobile,
Sydkraft,
TAC,
Thales,
Teleca AB,

Telelogic,
Tetra Pak Research & Development,
UPM-Kymmene,
Volvo Technical Development, and
VTT.

We have had smaller projects with

ABB Automation Techn. Products,
Absolut Vodka,
Alstom AG,
AssiDomän Cartonboard,
Axis Communications AB,
ConnectBlue,
DaimlerChrysler,
Ericsson Mobile Communication,
MA System,
Modo Paper Husum,
Pulp and Paper Industries Engineering Co. (STFI)
Stora Hylte AB,
TAC,
TeleLogic.

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 are also members of the Groupement Européen de Recherches Technologiques sur les Hydrocarbures (G.E.R.T.H.).

7. Looking Back on Adaptive Dual Control

In all control problems there are certain degrees of uncertainty with respect to the process to be controlled. The structure of the process and/or the parameters of the process may vary in an unknown way. There are several ways to handle these types of uncertainties in the process. One way to handle uncertainties is to use an adaptive controller, which attempts to identify or estimate the unknown parameters of the process. Most adaptive controllers have the structure shown in Figure 7.1, which is a self-tuning adaptive control system. The inputs and the outputs of the process are fed to the estimator block, which delivers information about the process to the controller design block. The design block uses the latest process information to determine the parameters of the controller. The adaptive controller thus consists of an ordinary feedback loop and a controller parameter updating loop. Different classes of adaptive controllers are obtained depending on the process information that is used in the controller and how this informa-

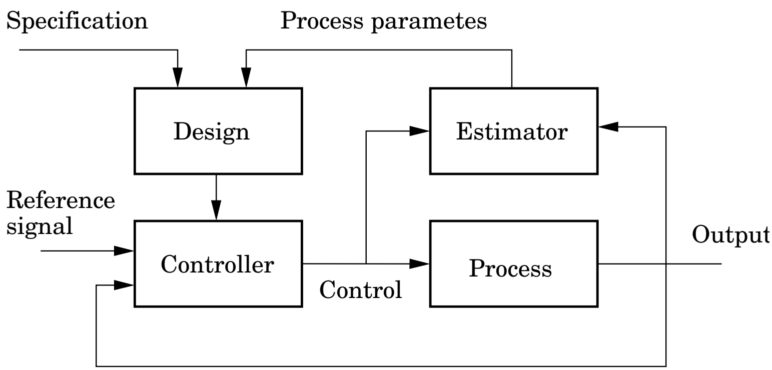


Figure 7.1 Self-tuning adaptive control system.

tion is utilized. In the self-tuning controllers the certainty equivalence principle is used. This implies that the estimated parameters are used as if the are the true ones when the controller design is done.

To obtain good process information it is necessary to perturb the process. Normally, the information about the process will increase with the level of perturbation. On the other hand the specifications of the closed loop system are normally such that the output should vary as little as possible. There is thus a conflict between information gathering and control quality. This problem was introduced and discussed by A. A. Feldbaum in a sequence of four seminal papers from 1960 and 1961, see [Feldbaum, 1960] and [Feldbaum, 1961]. Feldbaum's main idea is that in controlling the unknown process it is necessary that the controller has dual goals. First, the controller must control the process as well as possible. Second, the controller must inject a probing signal or perturbation to get more information about the process. By gaining more process information better control can be achieved in future time. The compromise between probing and control or in Feldbaum's terminology investigating and directing leads to the concept of *dual control*.

The dual control problem can be formulated as a stochastic adaptive control problem. The solution of the problem can be obtained using dynamic programming developed by R. Bellman, see, for instance, [Bellman, 1961]. In the end of the 1960s Åström and Bellman cooperated and there were mutual visits and exchanges between the department and Bellman's department at University of Southern California. The areas of stochastic adaptive control and dual control are reviewed in [Bellman, 1961], [Wittenmark, 1975b], [Åström and Wittenmark, 1995], [Wittenmark, 1995], [Filatov and Unbehauen, 2000], and [Veres and Wall, 2000]. In the sequel we will concentrate on the contributions in adaptive dual control from the department. Dual control is a problem area that researchers at the department have been returning to several times over the years. In this review we will discuss some of the approaches. The dual control problem is a problem where the increasing computing power has made it feasible to formulate and attack more and more realistic problem. The curse of dimensionality is still a great obstacle for the full understanding of dual control.

Stochastic adaptive control

To formulate the adaptive dual control problem we must specify the model for the process, the admissible control signals, and the specifications (loss function) for the closed loop system.

The process is described by the discrete time model

$$y(k+1) = f\left(u(k), \mathcal{Y}_k, \theta(k), \zeta(k)\right)$$

where $\zeta(k)$ is a stochastic process driving the process and/or the parameters of the process. The probability distribution of ζ is assumed known. This implies that the output at the next sampling instance, $k+1$ is a, possibly nonlinear, function of the control signal to be determined at time k, some, not necessarily all, of the elements in

$$\mathcal{Y}_k = \begin{bmatrix} y(k) & y(k-1) & u(k-1) & \ldots & y(0) & u(0) \end{bmatrix}$$

and of the unknown process parameters. It is assumed that the function $f(\cdot)$ is known. This implies that the structure of the process is known but that there are unknown parameters, $\theta(k)$. The performance of the closed loop system is measured by a loss function, that should be as small as possible. Assume that the loss function to be minimized is

$$J_N = \mathrm{E}\left\{ \frac{1}{N} \sum_{k=1}^{N} \left(y(k) - y_r(k)\right)^2 \right\}$$

where y is the process output, y_r is the reference signal, and E denotes mathematical expectation taken over the distribution of ζ. This is called an N-*stage criterion*. Instead of using a quadratic loss a general positive convex function can be used. The multi-objective purpose of the dual control problem, probing and control, is resolved by using a multi-step loss function instead of solving a multi-objective optimization problem.

The admissible controllers are causal functions of all information gathered up to time k, i.e. $\mathcal{Y}_k$. The loss function should be minimized with respect to the admissible control signals $u(0), u(1), \ldots, u(N-1)$.

The adaptive problem has now been turned into an optimization problem. The optimization problem for $N = 1$ is easy to solve when the process is linear in the parameters and when the loss function is quadratic. The resulting controller is called a *cautious controller* since the control signal will depend not only on $\mathcal{Y}_k$ and the parameter estimates $\hat{\theta}(k)$ but also on the variance of the parameter estimates $P(k)$. When the uncertainty increases, i.e. P becomes larger, the gain of the controller decreases. This can lead to turn-off of the control. The turn-off phenomena is due to the fact that the minimization of the loss function is done only one step ahead. There is then no gain for the controller to make any probing action to increase the knowledge of the uncertain parameters. The turn-off phenomena was observed in [Åström and Wittenmark, 1971] and some analysis of the phenomena was done in [Wittenmark, 1971]. Especially, it is of interest to find out the probability that the control action is turned on again. Feldbaum showed that a functional equation gives the solution to the dual control problem. The derivation is based on dynamic programming and the resulting functional equation is often called the *Bellman equation*, i.e. if a solution exists it must satisfy

$$V\left(\xi(k),\, k\right) = \min_{u(k-1)} J_k = \min_{u(k-1)} \mathrm{E}\Big\{ \left(y(k) - y_r(k)\right)^2 + V\left(\xi(k+1),\, k+1\right) |\mathcal{Y}_{k-1} \Big\}$$

where $V(\xi(k), k)$ can be interpreted as the minimum expected loss for the remaining part of the control horizon given data up to $k-1$.

Assuming a model that is linear in the parameters the separation principle is optimal. This implies that the estimation of the unknown parameters can be separated from the determination of the control signal. The optimal controller is decomposed into two parts: an estimator and a feedback controller. The estimator generates the conditional probability distribution of the state given the measurements $\mathcal{Y}_k$. This distribution is called the *hyperstate* of the process and is denoted $\xi(k)$. There is no distinction between the parameters and the other state variables in the hyperstate. The controller is then able to handle very rapid parameter variations.

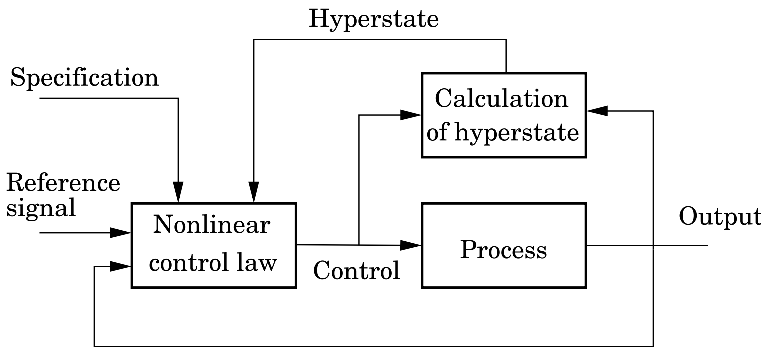


Figure 7.2 Block diagram of an adaptive controller obtained from stochastic control theory.

The feedback controller is a nonlinear function mapping the hyperstate into the control signal, see Figure 7.2. The hyperstate includes the parameter estimates, their accuracy, and old inputs and outputs of the system. Notice the similarity with the self-tuning controller in Figure 7.1. The structural simplicity of the controller is obtained thanks to the introduction of the hyperstate. The output signal is included in the hyperstate, but in Figure 7.2 the ordinary feedback loop is kept to further illustrate the similarity with an ordinary adaptive controller. Unfortunately, the hyperstate will be of very high dimension making the calculations difficult.

The difficulty with the Bellman equation is the nested minimization and mathematical expectation. The minimization is done over one variable, $u(k-1)$, but the problem is that the dimension of the hyperstate is very large, which complicates the minimization as well as evaluating the conditional expectation. Also it is difficult to give conditions for when the solution to the dynamic programming solution actually exists.

The choice of $u(k-1)$ influences the immediate loss, the future parameter estimates, their accuracy, and also the the future values of the outputs of the process. The controller will thus have the desired dual feature in contrast to the certainty equivalence and cautious controllers.

Except for very special cases the Bellman equation has to be solved numerically. Since both V and u have to be discretized it follows that the storage requirement increases drastically with decreasing grid size. Because of the difficulty of solving the Bellman equation only a few dual optimal control problems have been solved. The simplified case in which the process is described as a Markov chain is discussed in [Åström, 1965], [Åström, 1969], [Sternby, 1976], and [Sternby, 1977].

The case when the process is a delay and there is an unknown gain is solved numerically in [Åström and Wittenmark, 1971]. In the beginning of the 1970's the gain with delay was the complexity of the process that could be handled numerically with respect to storage and computation time. With better computers optimal dual control of an integrator with delay was numerically derived in [Helmersson, 1981], [Åström and Helmersson, 1982], [Åström and Helmersson, 1983], and [Åström and Helmersson, 1986]. In [Cervin, 1998] neuro-dynamic programming is used to determine the nonlinear control mapping. The numerical solutions of the very simple problems give, however, good insights into the properties of the dual nature of the optimal solutions. The resulting control law is nonlinear in the parameter estimates and the covariance matrix of the parameter estimates. The simple examples give useful indications how suboptimal dual controllers can be constructed.

To illustrate how the optimal dual controller can switch between probing and control consider Figure 7.3. In the figure the function J_k, which have several local minima, is given for three possible values of a scalar hyperstate. For the dashed curve the local minimum to the left gives the absolute minimum. We may regard this as the case where the controller is just cautious. For the full line case the two local minima have the same value, also the left local minimum is obtained for a lower value of u than for the dashed line. We may interpret this as the controller now is more cautious than before. Finally, for the dash-dotted curve the local minimum to the right represents the absolute minimum and the control signal becomes larger. This can be interpreted as the introduction of probing in the controller. The control action will thus switch in character when the hyperstate is changed. This can be interpreted as that the control action is switching between control and probing actions.

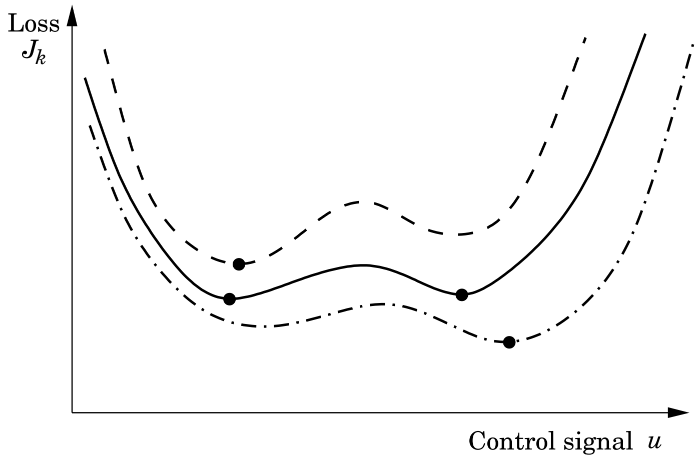


Figure 7.3 A possible shape of the loss J_k as function of the control signal u and for three different values of a scalar hyperstate ξ. The absolute minima for the three cases are marked by dots.

The minimization over several steps to obtain the dual controller makes it possible for the controller to have different types of actions during different parts of the control horizon. It is possible to introduce probing in the beginning of the time interval or when the information about the process is poor. The extra loss due to probing is compensated for in other parts of the control interval by now having obtained better information about the process. The total loss over the whole control horizon will then be lower than without probing.

Suboptimal dual controllers

The difficulties to find the optimal solution have made it interesting to find approximations to the loss function or to find other ways to change the controller such that a dual control feature is introduced.

Perturbation signals

The turn-off phenomenon is due to lack of excitation. The intentional addition of a perturbation signal is one way to increase the excitation of the process and to increase the accuracy of the estimates. Typical added signals are pseudo-random binary sequences, square-waves, and white noise signals. The perturbation can be added all the time or only when the uncertainty of a process parameter is exceeding some limit. Extra perturbation to avoid turn-off is discussed in [Wieslander and Wittenmark, 1971] and [Sternby, 1977]. The idea of probing was also used in [Åkesson, 1999] and [Åkesson *et al.*, 2001] in connection with finding feeding strategies in fed-batch bioreactors.

The addition of the extra signal will naturally increase the loss due to probing but may make it possible to improve the total performance by decreasing the control loss in future steps. A drawback with the introduction of the perturbation signal is that there is no systematic way of deciding when to add the signal and how large the signal should be.

Approximations of the loss function

One approach to obtain a suboptimal dual controller is to make a serial expansion of the loss function in the Bellman equation. The expansion can be done around the certainty equivalence or the cautious controllers. The numerical computations are, however, still quite complex and the approach has mainly been used when the control horizon is short.

Another approximation is to solve the two-step minimization problem ($N = 2$). A suboptimal dual controller with a two-step horizon is determined. The suboptimal dual controller modifies the cautious controller design by numerator and denominator correction terms which depend upon the sensitivity functions of the expected future cost and avoids the turn-off and slow convergence. The two step problem gives clues how to make sensible approximations that retain the dual features, see [Sternby, 1977], [Pernebo and Sternby, 1978], [Lindoff *et al.*, 1998], and [Lindoff *et al.*, 1999].

A third way to make an approximation of the loss function is to modify the available information in the evaluation of the loss function. One such modification is to assume that no further information will be available when evaluating the mean value in the Bellman equation. This type of controllers are called open-loop optimal feedback (OLOF) controllers.

Modifications of the loss function

An other approach is to extend the one-step-ahead loss function. The idea is to add terms in the loss function that are reflecting the quality of the parameter estimates. This will prevent the cautious controller from turning off the control. It is important to add as simple terms as possible to make it easy to numerically be able to find the resulting controller.

One possibility is to add terms depending on the covariance matrix of the parameter estimates. This leads to a loss function of the form

$$\mathrm{E}\left\{(y(k+1) - y_r(k+1))^2 \,|\mathcal{Y}_k\right\} + \lambda f\left(P(k+2)\right)$$

where λ is a weighting factor and $P(k+2)$ is the first time at which the covariance is influenced by $u(k)$. This suboptimal dual controller was developed in [Wittenmark, 1975a] and further analyzed in [Elevitch, 1983], [Wittenmark and Elevitch, 1985], [Sternby, 1977], [Lindoff *et al.*, 1998], and [Lindoff *et al.*, 1999]. The method works well for higher order systems, but its drawback is that λ is a tuning parameter.

Finite parameter sets

When the parameter set contains a finite number of elements it is easier to numerically solve the dual control problem. The number of possible combinations will be considerably reduced since the mathematical expectation in the Bellman equation is then replaced by a summation. The case with finite number of parameter values can be handled in the Markov chain formulation. First order systems with two possible values of the gain were treated in [Bernhardsson, 1988] and [Bernhardsson, 1989].

When to use dual control?

Non-dual adaptive controllers are successfully used today in many applications. When may it be advantageous to use a controller with dual features? One obvious situation is when the time horizon is short and when the initial estimates are poor. It is then necessary to rapidly find good estimates before reaching the end of the control horizon. It has been suggested that dual controllers are suitable for economic systems. The reason is the short time horizon and the highly stochastic parameters in the processes.

Another situation when to use dual control is when the parameters of the process are changing very rapidly. This is a situation that is not very common in practice. There are, however, processes where the parameters are changing fairly rapidly and the gain is also changing sign. This is the situation when the process has an even nonlinearity and it is desired to operate the process close to the extremum point. The gain of the linearized model will then change sign and at the same time some of the parameters may be small. One successful example reported in the literature is grinding processes in the pulp and paper industry, see [Dumont and Åström, 1988], [Allison, 1994], and [Allison *et al.*, 1995]. This application is probably the first true application of suboptimal dual control to process control. The controller is an active adaptive controller, which consists of a constrained certainty equivalence approach coupled with an extended output horizon and a cost function modification to get probing.

Summary

Despite the relative simplicity of the formulation of the dual control problem and the underlying functional equation it contains interesting facets of stochastic control, optimization, and numerical computations. The numerical solutions of very simple examples have give much insight and understanding of how to construct different types of suboptimal solutions. The problem area still contains many unsolved problems, but there have now been true industrial applications where it is of great advantage to assure that the controller have probing as well as controlling features.

The research on dual control at the department has been going on for many years and the knowledge about the solution of the problems has been obtained piece by piece. This shows the importance of having resources for long-term investigations.

Acknowledgments

The work on dual control has over the years been supported by NUTEK, including all its predecessors, TFR, and VR.

References

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

Åkesson, M., P. Hagander, and J. P. Axelsson (2001): "Probing control of fed-batch cultures: Analysis and tuning." *Control Engineering Practice*, **9:7**, pp. 709–723.

Allison, B. J. (1994): *Dual adaptive control of a chip refiner motor load*. PhD thesis, University of Brittish Columbia.

Allison, B. J., J. E. Ciarniello, P. J.-C. Tessier, and G. A. Dumont (1995): "Dual adaptive control of chip refiner motor load." *Automatica*, **31:8**, pp. 1169–1184.

Åström, K. J. (1965): "Optimal control of Markov processes with incomplete state information I." *Journal of Mathematical Analysis and Applications*, **10**, pp. 174–205.

Åström, K. J. (1969): "Optimal control of Markov processes with incomplete state information II." *Journal of Mathematical Analysis and Applications*, **26**, pp. 403–406.

Åström, K. J. and A. Helmersson (1982): "Dual control of a lower order system." In *Proc. National CNRS Colloque 'Développement et Utilisation d'Outils et Modèles Mathématiques en Automatique, Analyse de Systèmes et Traitement du Signal'.* Belle-Ile, France.

Åström, K. J. and A. Helmersson (1983): "A dual control of a low order system." In Landau, Ed., *Outils et Modeles Mathematiques pour l'Automatique l'Analyse de Systemes et le Traitement du Signal*, pp. 741–758. Editions du CNRS, Paris.

Åström, K. J. and A. Helmersson (1986): "Dual control of an integrator with unknown gain." *Comp. & Maths. with Appls.*, **12A:6**, pp. 653–662.

Åström, K. J. and B. Wittenmark (1971): "Problems of identification and control." *Journal of Mathematical Analysis and Applications*, **34**, pp. 90–113.

Åström, K. J. and B. Wittenmark (1995): *Adaptive Control*, second edition. Addison-Wesley, Reading, Massachusetts.

Bellman, R. (1961): *Adaptive Control Processes: A Guided Tour.* Princeton University Press, Princeton, N.J.

Bernhardsson, B. (1988): "Dual control of a first order dynamical system." In *Preprints The Nordic Section of SIAM Meeting on Industrial and Applied Mathematics*. University of Bergen, Norway.

Bernhardsson, B. (1989): "Dual control of a first-order system with two possible gains." *International Journal of Adaptive Control and Signal Processing*, **3**, pp. 15–22.

Cervin, A. (1998): "Dual control of an integrator using neuro-dynamic programming." Master thesis ISRN LUTFD2/TFRT--5598--SE. Department of Automatic Control, Lund Institute of Technology, Lund, Sweden.

Dumont, G. A. and K. J. Åström (1988): "Wood chip refiner control." *IEEE Control Systems Magazine*, April, pp. 38–43.

Elevitch, C. (1983): "An approximate analytical control law for an active suboptimal dual controller." Technical Report TFRT-7264.

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

Feldbaum, A. A. (1960): "Dual control theory I–II." *Automn Remote Control*, **21**, pp. 874–880, 1033–39.

Feldbaum, A. A. (1961): "Dual control theory III–IV." *Automn Remote Control*, **22**, pp. 1–12, 109–121.

Filatov, N. M. and H. Unbehauen (2000): "Survey of adaptive dual control methods." *IEEE Proc. Control Theory Appl.*, **147**, pp. 118–128.

Helmersson, A. (1981): "Dual reglering–En optimal dual regulator för en integrator med konstant men okänd förstärkning (Dual control–An optimal dual controller for an integrator with constant but unknown gain).". Master's thesis TFRT-5245, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden. (In Swedish).

Lindoff, B., J. Holst, and B. Wittenmark (1998): "Analysis of suboptimal dual control." In *IFAC Workshop on Adaptive Control and Signal Processing*, pp. 20–27. Glasgow, UK.

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

Pernebo, L. and J. Sternby (1978): "Simulations of two suboptimal dual controllers." *Int. J. Control*, **28**, pp. 545–556.

Sternby, J. (1976): "A simple dual control problem with an analytical solution." *IEEE Transactions on Automatic Control*, **AC-21**, pp. 840–844.

Sternby, J. (1977): *Topics in Dual Control.* PhD thesis TFRT-1012, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden.

Veres, S. M. and D. S. Wall (2000): *Synergy and Duality of Identification and Control.* Taylor & Francis, London.

Wieslander, J. and B. Wittenmark (1971): “An approach to adaptive control using real-time identification.” *Automatica*, **7**, pp. 211–217.

Wittenmark, B. (1971): “On the turn-off phenomenon in adaptive control.” Technical Report TFRT-3030. Department of Automatic Control, Lund Institute of Technology, Lund, Sweden.

Wittenmark, B. (1975a): “An active suboptimal dual controller for systems with stochastic parameters.” *Automatic Control Theory and Application*, **3**, pp. 13–19.

Wittenmark, B. (1975b): “Stochastic adaptive control methods: a survey.” *Int. J. Control*, **21:5**, pp. 705–730.

Wittenmark, B. (1995): “Adaptive dual control methods: An overview.” In *5th IFAC Symposium on Adaptive Systems in Control and Signal Processing*, pp. 67–72. Budapest, Hungary. Invited paper.

Wittenmark, B. and C. Elevitch (1985): “An adaptive control algorithm with dual features.” In *Preprints 7th IFAC/IFORS Symposium on Identification and System Parameter Estimation*, pp. 587–592. York, UK.

8. Dissertations

Two PhD theses were defended by Jonas Eborn and Mattias Grundelius; and one Lic Tech was completed by Johan Bengtsson.

The abstracts are presented here in chronological order.

On Model Libraries for Thermo-Hydraulic Applications

Jonas Eborn
PhD dissertation, March 2, 2001

Opponent: Prof. Heinz Presig, Systems & Control Group, Eindhoven University of Technology, The Netherlands. Committee: Prof. Alf Isaksson, S3, Processreglering, KTH, Stockholm, Sweden; Prof. Philip Thomas, dept. of Electric & Information Eng., City University, London, England; Dr. Mats Andersson, Volvo Technical Development, Gothenburg, Sweden.

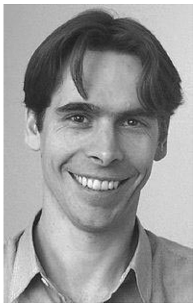
Mathematical modelling and simulation are important tools when dealing with engineering systems that today are becoming increasingly more complex. Tightly integrated production and process optimization are trends that give rise to heterogeneous systems, which are difficult to handle without expertise in several engineering disciplines. Model libraries provide an excellent way to package engineering knowledge of systems and units to be reused by non experts. Many commercial simulation packages provide good model libraries, but they are usually domain specific and closed. Heterogeneous, multi-domain systems requires open model libraries written in general purpose modelling languages. Modelica™ is such an open standard for an object-oriented modelling language for dynamic systems.

The thesis describes principles for object-oriented equation-based model libraries. The main topic is modelling of thermo-hydraulic applications. Two different model libraries are presented, the OMOLA model library **K2** for thermal power plants and the Modelica base library ThermoFlow for general thermo-hydraulic applications. The models are based on first principles. Lumped or 1D-discretized control volumes contain the thermodynamic balance equations. The base library is built for flexibility; the control volume can have different medium descriptions, single- or multi-component, and the momentum dynamics can be replaced by static descriptions. Some applications of the libraries are also described: a heat recovery steam generator, a drum-boiler model and a model of evaporating two-phase flow in a pipe.

The thesis consists of four articles. Papers I and II describe the two model libraries. Paper III covers the two-phase flow application and gives a simplified physical analysis that shows under what conditions there will be pressure-drop oscillations in an evaporating pipe. Model libraries for industrial use must be validated against measured data. Paper IV describes how parameter estimation methods can be used for model structure validation. The thesis also has a short discussion on other model validation methods.

Methods for Control of Liquid Slosh

Mattias Grundelius
PhD dissertation, October 26, 2001



Opponent: Prof. Torkel Glad, Linköping University, Linköping, Sweden. Committee: Prof. Pierre Rouchon, Ecole des Mines de Paris, France; PhD Ola Dahl, Malmö University, Malmö; PhD Steve Murphy, ABB Robotics, Gothenburg, Sweden, PhD Ebbe Lundgren, Lund Institute of Technology, Mechanics, Lund, Sweden.

Horizontal movement of liquid containers is a common operation in an industrial packaging machine. During the movement the acceleration of the container induces motion of the liquid within the container, this is referred to as liquid slosh or liquid vibration. If there is too much slosh the liquid might wet the sealing surfaces of the container and even contaminate the machine. There is no measurement of the slosh so the only way to control the slosh is through the acceleration reference that defines the movement.

The work presented in this thesis is focused on development of systematic methods for calculation of acceleration references that move the container as fast as possible without too much slosh. The methods are based on a simple model of the slosh phenomenon which is derived from fluid dynamics and system identification. The acceleration reference is calculated both directly using optimal control techniques with various cost functions and constraints and iteratively using iterative learning control.

To enable practical evaluation of the acceleration references and the use of iterative learning control an experimental setup has been used where it is possible to measure the surface elevation on one side of the container using an infrared laser displacement sensor. The experimental evaluations show that it is possible to achieve fast movements by solving a minimum energy optimal control problem and tuning of the model parameters. It is also shown that the iterative learning control methods are successful in finding good acceleration references in practice using only a simple model of the slosh phenomenon.

A method that utilize tilting of the container is also derived, this enables faster movements with less slosh. The methods simultaneously calculates the horizontal and rotational acceleration references by solving a minimum energy optimal control problem. Experiments show that the method is successful if the maximum allowed surface elevation is not too large.

Adaptive Cruise Control and Driver Modeling

Johan Bengtsson
Lic Tech dissertation, November 30, 2001

Opponent: Prof. Lars Nielsen, ISY, Linköping University, Linköping, Sweden.

Many vehicle manufacturers have lately introduced advance driver support in some of their automobiles. One of those new features is Adaptive Cruise Control (ACC), which extends the conventional cruise control system to control of relative speed and distance to other vehicles. In order to design an ACC controller it is suitable to have a model of driver behavior.

The approach in the thesis is to use system identification methodology to obtain dynamic models of driver behavior useful for ACC applications. Experiment with seven drivers participating in various different traffic situations were performed both on public road and on a test track. Data analysis was made by means of system identification methodology, several models of drivers' longitudinal behavior being proposed, including linear regression models, subspace-based models and behavioral models.

The thesis also deals with detection of when a driver is changing his behavior in various situations to a deviant behavior. To that purpose, a GARCH model was used to model the driver in situations with time-varying behavior.

9. Honors and Awards

On May 2, 2001 **Karl Johan Åström** was given the “Medaglia Teresiana” from University of Pavia.

Karl Johan Åström was elected as a foreign member of the Hungarian Academy of Sciences.

10. Personnel and Visitors

Personnel

During 2001 the following persons have been employed at the department. The list shows the *status of December 2001* if nothing else is mentioned.

Professors

Karl-Erik Årzén
Karl Johan Åström (emeritus)
Bo Bernhardsson *(on leave from May 1)*
Per Hagander
Tore Hägglund
Rolf Johansson
Anders Rantzer
Björn Wittenmark

Assistant Professors

Jonas Eborn *(April 1–September 30)*
Erik Möllerstedt *(until February 25)*

Associate Professor

Anders Robertsson

Research Engineers

Leif Andersson
Anders Blomdell
Rolf Braun

Guest Professors

Andrey Gulchak
Naomi Leonard

PhD Students

Johan Åkesson
Johan Bengtsson
Anton Cervin
Lena de Maré
Jonas Eborn *(until March 31)*
Mattias Grundelius *(until November 16)*
Magnus Gäfvert
Sven Hedlund
Dan Henriksson
Ari Ingimundarson
Bo Lincoln
Rasmus Olsson
Tomas Olsson *(from December 1)*
Mikael Petersson
Henrik Sandberg
Ola Slätteke
Stefan Solyom
Jacob Svendenius
Hubertus Tummescheit
Stéphane Velut

Secretaries

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.

Francesca Ceragioli *January 18–April 18, 2001*
Politecnico di Torino, Torino, Italy

Zhiyang Geng *from March 15, 2001*
Peking University, Beijing, China

Naomi Leonard *February 6–July 18, 2001*
Princeton University, Princeton, NJ, USA

Dan Block *May 31–June 14, 2001*
University of Illinois, USA

Abdulla Ismail *July 22–August 15, 2001*
United Arab Emirate

Eesa Bastaki *July 22–August 15, 2001*
United Arab Emirate

Alexander Megretski *August 13–August 17, 2001*
Massachusetts Institute of Technology, USA

Enrique Arias Antunez *September 8–December 7, 2001*
University of Castilla La Mancha, Spain

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

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

Luis Manuel Conde Bento (E) *until June 2001*
Universidade de Coimbra, Portugal

Antonio Gomez Perez (E) *until April 2001*
Universidad Politecnica de Cartagena, Spain

Duarte Mendonca (E) *until June 2001*
Universidade de Coimbra, Portugal

Domenico Scalamogna (E) *until July 2001*
Universita degli Studi, Firenze, Italy

Michail Bourmpos (E) *until September 2001*
Imperial College, London, UK

Leo Siang Kwong (B) *until March 2001*
National University of Singapore, Singapore

Francesco Calugi (E) *from October 2001*
University of Florence, Florence, Italy

Jose Luis de Mena (E) *from September 2001*
Universidad de Valladolid, Valladolid, Spain

Susana Santos (E) *until April 2001*
Universidad de Valladolid, Valladolid, Spain

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, Johan

MSc, graduate student since January 2001. Johan's main research interest is in the field of decision support structures for chemical process industry. He is currently working in the EC sponsored project CHEM. Johan's research interests also include stabilization of unstable systems subject to input saturation. During 2001, Johan was a teaching assistant in the courses Systems Engineering and Automatic Control basic course.

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 in 2000, PhD in 1987: Joined the department in 1981. His research interests 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 and for the VR 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 CHEM project on decision support systems for the process industries and in the SSF/ARTES project. He has been responsible for and taught the undergraduate course on Real-Time Systems and the International Project Course in Automatic Control. He is partly or fully involved in the supervision of six PhD students.

Bengtsson, Johan

Lic Tech in November 2001, graduate student since April 1999. He is interested in system identification, modeling and visual servoing. Johan is working in cooperation with Volvo Technical Development on driver models. During the year he has been teaching assistant in the Automatic Control basic course.

Bernhardsson, Bo

PhD 1992, Docent in 1998, and Professor in December 1999. Bo was chairman of education committee for Industrial Economics until March 31. Since May 1 he is on leave working at Ericsson Mobile Platforms in Lund. During 2001 he was also member of the educational board for Engineering Physics.

Blomdell, Anders

Research Engineer since 1988. Responsible for the department network and lab computers for teaching and research. Professional interest includes man-machine interaction, real-time programming, hardware design, communication protocols, and computer languages for control engineering. During the 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 the year he has been a teaching assistant in the courses Computer-Controlled Systems and Real-Time Systems. In September he spent four weeks with the Ptolemy research group, headed by Professor Edward Lee, at the Department of Electrical Engineering and Computer Sciences, University of California at Berkeley. Anton also visited Professor Lui Sha at the Department of Computer Science, University of Illinois at Urbana-Champaign, for one week in October.

de Maré, Lena

MSc, graduate student since August 1999. She is interested in control of biotechnical processes and is working together with Stéphane Velut and Per Hagander in the project "Process control for cultivation of genetically modified micro-organisms" funded by Vinnova. In collaboration with SBL Vaccin she has been working with *V. cholerae*. During 2001 she has been a teaching assistant in Automatic Control, basic course.

Eborn, Jonas

PhD in March 2001, graduate student since 1995. Interested in computer aided control engineering, physical system modeling and numerical analysis. During the spring term 2001 he was teaching assistant in the graduate course Physical Modeling of Dynamic Systems. Jonas left the department in September to work with United Technology Research Center i Hartford, USA.

Gäfvert, Magnus

MSc, graduate student since July 1996. Magnus is interested in topics on distributed control and real-time systems. Current work deals primarily with automotive applications. During the year he has worked on a case study on a truck braking system, provided by Volvo Technological Development within the NUTEK project DICOSMOS. This work includes modeling of tractor-semi trailer vehicles,and studies on unilateral braking strategies for anti-skidding control of articulated heavy-duty vehicles. Magnus spends one week per month at Volvo TD in Gothenburg. Another topic is the study of the effects on closed-loop performance of transient hardware-faults in processors executing control-algorithms in safety-critical control systems. 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 also 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 Magnus was a teaching assistant in System Identification and Real-Time Systems.

Gulchak, Andrey

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

In 2001 he has been teaching the courses Linear System I and Optimization by Vector Space Methods (the latter with Anders Rantzer) for PhD students. Andrey has participated in the European Control Conference, Porto, Portugal and the IEEE Conference on Decision and Control, Orlando, USA.

Grundelius, Mattias

PhD in October. 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. Mattias left the department in November to work with TAC AB in Malmö.

Hagander, Per

Professor, PhD (1973). Per has been with the department since 1968 and works with linear system theory and with applications in biotechnology and medicine.

Per Hagander is the LTH vice rector of international affairs. He was responsible for the course Computer Controlled Systems.

Since May 1996 Per is leading a project with Pharmacia AB, on multivariable control of genetically engineered *E. coli*. The work is also a collaboration with the Department of Biotechnology, Lund University and SBL Vaccine. Here Per works with Stéphane Velut, and Lena de Maré.

During the year he also participated in the LTH-course “Pedagogical Inspiration”.

Hägglund, Tore

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

Main research activities during the year have been design of PID controllers, and development and implementation of supervisory functions for process control.

Hedlund, Sven

Lic Tech, graduate student since 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 2001, Sven has been a teaching assistant in two undergraduate courses, Adaptive Control and the basic course in Automatic Control.

During winter 2001, he visited CWI, Amsterdam, The Netherlands, where he worked with Jan H. van Schuppen.

Henriksson, Dan

MSc, graduate student since December 2000. Dan's research interests concern design and analysis of real-time control systems. During 2001 Dan has been teaching assistant in the Automatic Control basic course and Real-Time Systems.

Ingimundarson, Ari

Graduate student since November 1998. His research interest include process control, automatic tuning and performance monitoring. The main research topics this year have been comparison of dead-time compensators and PID controllers and performance monitoring of feedback controllers. Ari was a teaching assistant in System Identification in Spring 2001.

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. for the two courses System Identification and Nonlinear Control and Servo Systems in the engineering program. Together with Dr. Måns Magnusson he leads research at the Vestibular Laboratory, Dept. Otorhinolaryngology, Lund University Hospital.

Lincoln, Bo

MSc, graduate student since February 1999. He is working on control problems from the networked control domain. The two major types of problems are delays (possibly random), and switching or scheduling problems. The latter is done with his advisor Anders Rantzer, and connects to the hybrid control world. He has been a teaching assistant in the basic control course three times, and in the course in nonlinear systems twice. Bo has also been in the working group for the new digital control course.

Mårtensson, Britt-Marie

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

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. In February Erik left the department to work for DECUMA AB in Lund.

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 course Automatic Control and Automatic Process Control.

Petersson, Mikael

Graduate student since 1997. Petersson is employed by ABB Automation Technology Products 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, and cascade control. Currently, a test implementation of the ideas is done in ABB's control system Control^{IT}. The control systems is then connected to the laboratory processes of the department for tests and evaluations.

Rantzer, Anders

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

During 2001, Anders Rantzer was the main supervisor for the PhD students Eborn, Hedlund, Lincoln, Sandberg, Solyom and Tummescheit and served on several committees within the university. He gave two plenary lectures at international conferences and was member of two program committees and one steering committee for other international conferences. Rantzer also served an evaluation board at the Swedish Research Council.

Robertsson, Anders

Assistant Professor from May 2001, PhD 1999. His main interest is in nonlinear control and robotics. Currently he is working on sensor-data integration and force control of industrial robots in collaboration with ABB Robotics. The research has been conducted with the LUCAS project and the Robotics Lab. He has lectured the basic course of Automatic Control for electrical engineers, a project course in Robotics and acted as advisor for several Master's Thesis projects and student projects.

Sandberg, Henrik

MSc, graduate student since January 2000. He is interested in analysis, reduction, and control of periodic and time-varying systems. He is working in the project "Reduction and aggregation of process models" within the CPDC-graduate-school and the VR-project "Theory for modeling, control and analysis of periodic systems" in cooperation with the mathematics department in Lund.

Henrik has been teaching assistant in the basic Automatic Control course and the Real-Time Systems course during the year. During the spring he spent four months at Caltech in Pasadena as a guest graduate student working with the multi-vehicle wireless testbed research group.

Schildt, Eva

Secretary at the Department since 1970. Eva is mainly responsible for the financial transactions of the department such as bookkeeping and reporting to our sponsors. She handles the personnel administration and takes care of the administration concerning visitors at the department.

Slätteke, Ola

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

Solyom, Stefan

MSc, graduate student since August 1999. His research interest is in nonlinear and hybrid control strategies. In particular, he is interested in piecewise linear systems. During the year he has worked on an Antilock Braking System within the ESPRIT project H^2C. Here, tests have been carried out in cooperation with DaimlerChrysler. Stefan has also been teaching in the courses Digital Control, Automatic Control, basic course, and in Engineering Process.

Svendenius, Jacob

MSc in mechanical engineering. He started to work in the laboratory at Haldex Brake Product AB in 1998. He has mainly worked with performance testing of brakes and heavy vehicles. In 2001 Jacob started to work at the department in a project supported by Haldex.

Tummescheit, Hubertus

Graduate student since 1996, graduate student in Lund since 1998. Interested in physical system modeling, modeling language design and numerical analysis. Since 1997 he is a member of the Modelica Association which continuously works on the advancement of the Modelica physical systems modeling language. During 2001 he has been teaching assistant in two basic control courses. He has also supervised two Master's theses on modeling of gas turbine systems 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. Agneta is also responsible for Activity Report 2001 together with Rolf Johansson.

Velut, Stéphane

Graduate student since July 1999. He is interested in control of biotechnological processes and extremum control. He is working together with Lena de Maré and Per Hagander in the Vinnova project "Process control for cultivation of genetically modified micro-organisms". Stéphane has been teaching assistant in the undergraduate courses Systems Engineering and Automatic Control.

Wittenmark, Björn

Professor in Automatic Control since 1989. He joined the department in 1966 and took his PhD in 1973. His main research interests are adaptive control, sampled-data systems, and process control. He is working within the projects "Timing Problems in Real-time Systems", and "Center for Chemical Process Design and Control". Björn was also chairman of the department during Jan–June 2001 and from July he is on sabbatical leave.

External Assignments

Opponent and Member of Examination Committee

Karl-Erik Årzén: External opponent on the licentiate thesis by Magnus Hellring, School of Electrical and Computer Engineering, Chalmers/University of Halmstad, Sweden, March 21. Chairman of the examination board of the PhD thesis by Per Tunestål, Department of Heat and Power Engineering, Lund Institute of Technology, Lund, Sweden, April 6. External opponent on the licentiate thesis by Bengt Öhman, Department of Information Technology, Lund Institute of Technology, Lund, Sweden, May 23.

Bo Bernhardsson: Member of the Examination Committee for Mats Larsson, Industrial Electrical Engineering and Automation, Coordinated Voltage Control in Electrical Power Systems, January. Member of the Examination Committee for Erik Thunberg, Power Systems, On the benefit of Harmonic Measurement in Power Systems, KTH, Stockholm, Sweden, October.

Per Hagander: External reviewer for the PhD-thesis by Kurt Creutzburg, DTU, June 19.

Rolf Johansson: Opponent on the PhD thesis by Bert Haverkamp, Dept. Electrical Engineering, TU Delft, Delft, The Netherlands, February 13. Opponent on the licentiate thesis by Per Östborn, Dept. Mathematical Physics, Lund University, Lund, May 2.

Anders Rantzer: External opponent on the PhD thessis by Georgo Angelis, Eindhoven University of Technology, Eindhoven, The Netherlands, February 6. Member of the Examination Committee for PhD thesis by Klaus Trangbaek, Aalborg University, Aalborg, Denmark, June 14. Member of the Examination Committee for PhD thesis by Fredrik Kahl, Department of Mathematics, Lund university, Lund, Sweden, September 21.

Board Member

Karl-Erik Årzén: Member of the Board of SSF ARTES program, the Swedish real-time systems research network. Member of the Board of SNART (Swedish National Association for Real-Time Systems).

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

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

Hubertus Tummescheit: Member of the Modelica Design Group, webmaster of the Modelica Web pages.

Björn Wittenmark: Board member of Lunds Datacentral, LDC, (Lund University Computing Center), Board member of the Research Board FIME–Physics, Informatics Mathematics and Electrical Engineering, Lund Institute of Technology, Lund, Sweden. Board member of LUCAS–Center for Applied Software Research. President elect and board member of the Royal Physiografic Society, Lund, Sweden. Member of the Disciplinary Committee at Lund University, Lund, Sweden. Expert member in legal proceedings for patent at Svea Court of Appeal, 2001–2003. Swedish representative of European Union Control Association (EUCA) Council. Chairman and Lecturer in the IEEE Control Society Distinguished Lectures Program.

Book and Journal Editor

Tore Hägglund: Associate editor for Control Engineering Practice.

Rolf Johansson: Associate editor of Int. J. Adaptive Control and Signal Processing.

Anders Rantzer: Associate editor of Systems and Control Letters.

Björn Wittenmark: Member of the Editorial Board: Optimal Control Applications & Methods, Journal of Forecasting, International Journal of Adaptive Control and Signal Processing, and Springer series on Advances in Industrial Control.

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.

Anders Rantzer: Member of IEEE CSS Tech. Com. on Nonlinear Systems and Control. Björn Wittenmark: Chairman of the committee for IFAC Control Engineering Practice Price. Member of the Technical committee for IFAC Adaptive Control and Learning.

Member of International Program Committee (IPC)

Tore Hägglund: Member of the International Program Committees for the conference Control Systems 2002 in Stockholm, and for the conference Controlo 2002, 5th Portugese Control Conference.

Rolf Johansson: Member of IPC IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM'01), Como, Italy, July 2001. Member of IEEE International Conference on Mechatronics and Machine Vision in Practice (M2VIP 2001), Hong Kong, China, August 2001.

Anders Rantzer: Member of IPC for European Control Conference 2003. Member of IPC for 4th IFAC Symposium on Robust Control Design (ROCOND-2003). Member of IPC for 5th Int. Workshop: Hybrid Systems: Computation and Control, 2002.

Björn Wittenmark: Member of the International Program Committee for IFAC Workshop on Adaptation and Learning in Control and Signal Processing, Cernobbio–Como, Italy, August. Member of the International Program Committee for European Control Conference ECC'2001, Porto, Portugal, September. Member of the International Program Committee for IFAC Workshop "Internet Based Control Education (IBCE'01)", Madrid, Spain, December.

Other Assignments

Rolf Johansson: During May 7–11, Rolf Johansson gave a graduate course on adaptive control at Rice University, Houston, TX, USA.

During August 2001 Rolf Johansson was visiting professor at Norwegian University of Science and Technology, NTNU, Trondheim, Norway.

Björn Wittenmark: During October–November 2001 Björn Wittenmark was visiting professor at Department of Electrical and Electronic Engineering, University of Melbourne, Australia.

12. Publications and Conference Contributions

1 book contribution, 16 journal papers and 21 conference contributions have been published this year.

Book Contributions

Åström, Karl Johan, and Björn Wittenmark: "On self-tuning regulators." In Basar, Ed., *Control Theory: Twenty-five seminal papers*. IEEE Press, 2001. Reprint of paper from Automatica vol 9, pages 185–199.

Journal Papers

Åkesson, M., P. Hagander, and J. P. Axelsson: "Avoiding acetate accumulation in *Escherichia coli* cultures using feedback control of glucose feeding." *Biotechnology and Bioengineering*, **73:3**, pp. 223–230, 2001.

Åkesson, M., P. Hagander, and J. P. Axelsson: "Probing control of fed-batch cultures: Analysis and tuning." *Control Engineering Practice*, **9:7**, pp. 709–723, 2001.

Åström, Karl Johan: "Control problems in paper making: Revisited." *Pulp & Paper Canada*, **102:6**, pp. 39–44, 2001.

Åström, Karl Johan, and Tore Hägglund: "The future of PID control." *Control Engineering Practice*, **9**, pp. 1163–1175, 2001.

Carlson, J., R. Johansson, and S. B. Olsson: "Classification of electrocardiographic P-wave morphology." *IEEE Transactions on Biomedical Engineering*, **48:4**, pp. 401–405, 2001.

Collado, J., R. Lozano, and R. Johansson: “On the Kalman-Yakubovich-Popov lemma for stabilizable systems.” *IEEE Transactions on Automatic Control*, **46:7**, pp. 1089–1093, 2001.

Hägglund, Tore: “The Blend station - a new ratio control structure.” *Control Engineering Practice*, **9**, pp. 1215–1220, 2001.

Ingimundarson, Ari, and Tore Hägglund: “Robust tuning procedures of dead-time compensating controllers.” *Control Engineering Practice*, **9**, pp. 1195–1208, 2001.

Johansson, R., A. P. Krishchenko, D. A. Sidorov, and S. B. Tkachev: “Stabilizatsiya affinnykh sistem ogrannichennym upravleniem (Stabilization of affine systems with saturating control).” *Vestnik Moskovskogo Gosudarstvennogo Tekhnicheskogo Universiteta*, **2:7**, pp. 31–45, 2001.

Johansson, R., M. Magnusson, P. A. Fransson, and M. Karlberg: “Multi-stimulus multi-response posturography.” *Mathematical Biosciences*, **174**, November, pp. 41–59, November 2001.

Johansson, R., M. Verhaegen, C.T. Chou, and A. Robertsson: “Residual models and stochastic realization in state-space identification.” *International Journal of Control*, **74:10**, pp. 988–995, July 2001.

Olsson, Henrik, and Karl Johan Åström: “Friction generated limit cycles.” In *IEEE Transactions on Control Systems Technology*, vol. 9, pp. 629–636, July 2001.

Pedersen, L. M., and B. Wittenmark: “A simple slab temperature model.” *Steel Technology International*, pp. 74–78, 2001.

Rantzer, A.: “A dual to Lyapunov’s stability theorem.” *Systems & Control Letters*, **42:3**, pp. 161–168, February 2001.

Rantzer, A.: “Friction analysis based on Integral Quadratic Constraints.” *Int. Journal of Robust and Nonlinear Control*, **11**, pp. 645–652, 2001.

Rengaswamy, R, T. Hägglund, and V. Venkatasubramanian: “A qualitative shape analysis formalism for monitoring, control loop performance.” *Engineering Applications of Artificial Intelligence*, **14:1**, pp. 23–33, 2001.

Conference Papers

Åkesson, Johan, and Karl Johan Åström: "Safe manual control of the Furuta pendulum." In *Proceedings 2001 IEEE International Conference on Control Applications (CCA'01)*, pp. 890–895, Mexico City, Mexico, September 2001.

Åkesson, M., P. Hagander, and J. P. Axelsson: "An improved probing controller for substrate feeding in fed-batch culteres of *E. coli*: simulations and experiments." In Dochain and Perrier, Eds., *Proceedings of the 8th International Conference on Computer Applications in Biotechnology, June 24–27, 2001, Quebec City, Canada.*, pp. 219–224, 2001. CAB8, Montreal, June 2001.

Bengtsson, Johan, Rolf Johansson, and Agneta Sjögren: "Modeling of drivers longitudinal behavior." In *2001 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM'01)*, Como,Italy, 2001.

de Maré, L., S. Velut, P. Hagander, and M. Åkesson: "Feedback control of flow rate from a peristaltic pump using balande measurements." In *European Control Conference EC2001*, Porto, Portugal, September 2001.

Eker, Johan, Anton Cervin, and Andreas Hörjel: "Distributed wireless control using Bluetooth." In *Proceedings of the IFAC Conference on New Technologies for Computer Control*, Hong Kong, P.R. China, 2001.

Gäfvert, Magnus, and Karl-Erik Årzén: "Control of gasoline direct injection engines using torque feedback." In *NACO2 Workshop on Automotive Control*, 2001.

Ghulchak, Andrey: "Dual problem in multi-objective h^p control." In *Proceedings of European Control Conference*, Porto, Portugal, September 2001.

Ghulchak, Andrey: "Duality in robust control: Controller vs. uncertainty." In *Proceedings of IEEE Conference on Decision and Control*, Orlando, Florida, December 2001.

Henriksson, Dan, Rolf Johansson, and Anders Robertsson: "Observer-based impedance control in robotics." In *Proceedings of the 5th IFAC Symposium "Nonlinear Control Systems" (NOLCOS'01)*, pp. 365–370, St. Petersburg, Russia, July 2001.

Henriksson, Dan, Rolf Johansson, and Anders Robertsson: "Observer-based impedance control in robotics." In *Proceedings of the 5th IFAC Symposium "Nonlinear Control Systems" (NOLCOS'01)*, pp. 365–370, St. Petersburg, Russia, July 2001.

Johansson, R., P. A. Fransson, and M. Magnusson: "Identification of adaptation in human postural control using GARCH models." In *Proc. IEEE Conf. Decision and Control (CDC 2001)*, pp. 7–12, Orlando, FL, December 2001. Invited Paper.

Johansson, R., and A. Robertsson: "Observer-based SPR feedback control system design." In *Proceedings of the 5th IFAC "Nonlinear Control Systems Design Symposium" (NOLCOS'01)*, pp. 1601–1606, St.Petersburg, Russia, July 2001.

Lincoln, Bo, and Anders Rantzer: "Optimizing linear system switching." In *Proceedings of the 40th Conference on Decision and Control*, Orlando, USA, dec 2001.

Petersson, Mikael, Karl-Erik Årzén, and Tore Hägglund: "Assessing measurements for feedforward control." In de Carvalho, Ed., *European Control Conference–ECC'01*, pp. 432–437, Porto, Portugal, September 2001.

Rantzer, Anders: "Almost global stability of phase-locked loops." In *Proceedings of IEEE Conference of Decision and Control*, Orlando, December 2001.

Rantzer, Anders, and Francesca Ceragioli: "Smooth blending of nonlinear controllers using density functions." In *Proceedings of European Control Conference*, 2001.

Sandberg, Henrik, and Erik Möllerstedt: "Periodic modelling of power systems." In *Proceedings of the IFAC Workshop on Periodic Systems and Control*, Cernobbio-Como, Italy, 2001.

Santos, S., J. Carlson, E. Hertevig, S. B. Olsson, and R. Johansson: "System identification applied to spatial and temporal propagation of atrial activity during atrial fibrillation." In *Proc. IEEE Conf. Decision and Control (CDC 2001)*, pp. 855–860, Orlando, FL. Invited Paper.

Tunestål, P., J. K. Hedrick, and R. Johansson: "Model-based estimation of cylinder pressure sensor offset using least-squares methods." In *Proc. IEEE Conf. Decision and Control (CDC 2001)*, pp. 3740–3745, Orlando, FL.

Wittenmark, B.: "Sample-induced delays in synchronous multirate systems." In *European Control Conference*, pp. 3276–3281, Porto, Portugal, 2001. September.

13. Reports

During this year 2 PhD theses and 1 Lic Tech thesis have been published. The abstracts are presented in Chapter 8. Also 23 master theses and 6 internal reports have been completed.

Dissertations

Bengtsson, Johan: *Adaptive Cruise Control and Driver Modeling*. Lic Tech thesis ISRN LUTFD2/TFRT--3227--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 2001.

Eborn, Jonas: *On Model Libraries for Thermo-hydraulic Applications*. PhD thesis ISRN LUTFD2/TFRT--1061--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 2001.

Grundelius, Mattias: *Methods for Control of Liquid Slosh*. PhD thesis ISRN LUTFD2/TFRT--1062--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, October 2001.

Master Theses

Bourmpos, Michail: "Vision based robotic grasping tracking of a moving object." Master thesis ISRN LUTFD2/TFRT--5675--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 2001.

Carlsson, Gert-Ola: "Statecharts in ABB Control-IT." Master thesis 5681, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 2001.

Chatila, Wael: "Producing periodic motion for underactuated systems." Master thesis ISRN LUTFD2/TFRT--5669--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, April 2001.

Conde Bento, Luis, and Duarte Mendonca: "Computer vision and kinematic sensing in robotics." Master thesis ISRN LUTFD2/TFRT--5670--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, June 2001.

Eklund, Pia, and Marianne Tufvesson: "Predictive control of irrigation channels." Master thesis ISRN LUTFD2/TFRT--5661--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, February 2001.

Ekstrand, Andreas, and Jonas Ludvigsson: "Generic web server in embedded control systems." Master thesis ISRN LUTFD2/TFRT--5678--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 2001.

Fredriksson, John: "Probing control of glucose feeding in cultivation of *Saccharomyces cerevisiae*." Master thesis ISRN LUTFD2/TFRT--5660--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, January 2001.

Fridman, Helena, and Telina Englund: "Medical image registration." Master thesis ISRN LUTFD2/TFRT--5662--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, February 2001.

Göransson, Anders: "Active control of combustion instabilities." Master thesis ISRN LUTFD2/TFRT--5664--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, February 2001.

Hansen, Carina, and Cecilia Svensson: "Construction and control of an inverted pendulum." Master thesis ISRN LUTFD2/TFRT--5679--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, July 2000.

Hjerpe, Magnus: "Analysis of body kinematics and force modulation." Master thesis ISRN LUTFD2/TFRT--5677--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 2001.

Holmberg, Fredrik: "Implementation of a PID controller for building automation." Master thesis ISRN LUTFD2/TFRT--5665--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 2001.

Hörjel, Andreas: "Bluetooth in control." Master thesis ISRN LUTFD2/TFRT--5659--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, January 2001.

Johansson, Per: "An adaptive PPI controller." Master thesis ISRN LUTFD2/TFRT--5674--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 2001.

Kwong, Leo Siang: "Automatic test system for network servers." Master thesis ISRN LUTFD2/TFRT--5663--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 2001.

Naef, Emil: "Hard real-time and synchronous programming with SDL." Master thesis ISRN LUTFD2/TFRT--5671--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, April 2001.

Öberg, Markus: "Optimizing operation times in a storage control system." Master thesis ISRN LUTFD2/TFRT--5680--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 2001.

Olsson, Tomas: "Vision guided force control in robotics." Master thesis ISRN LUTFD2/TFRT--5676--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, October 2001.

Pérez, Antonio Alejandro Gómez: "Modelling of a gas turbine with Modelica." Master thesis ISRN LUTFD2/TFRT--5668--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 2001.

Santos, Susana: "System identification applied to cardiac activation." Master thesis ISRN LUTFD2/TFRT--5666--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, April 2001.

Scalamogna, Domenico: "Iterative learning control with application to robotics." Master thesis ISRN LUTFD2/TFRT--5672--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, June 2001.

Talborn, Henrik: "Investigation of a closed loop modulator for bluetooth radios." Master thesis ISRN LUTFD2/TFRT--5667--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, April 2001.

Wallén, Lars: "Dynamic tyre models in adaptive slip control." Master thesis ISRN LUTFD2/TFRT--5673--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 2001.

Other Reports

Årzén, Karl-Erik, and Agneta Tuszyński: "Automatic Control 2000. Activity report." Report ISRN LUTFD2/TFRT--4028--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, June 2001.

Åström, Karl Johan: "Modeling of dynamic systems applications to physics, engineering, biology, and social science." Report ISRN LUTFD2/TFRT--7594--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 2001.

Blomdell, Anders: "Efficient Java™Monitors." Report ISRN LUTFD2/TFRT--7593--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, 2001.

Gäfvert, Magnus: "Modelling of the ETH helicopter laboratory process." Report ISRN LUTFD2/TFRT--7596--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, 2001.

Johansson, R., A. P. Krishchenko, D. A. Sidorov, and S.B. Tkachev: "Stabilization of affine systems with saturation control." Report ISRN LUTFD2/TFRT--7595--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, 2001.

Wittenmark, Björn, and Robin Evans: "Extremal Control of Wiener Model Processes." Report ISRN LUTFD2/TFRT--7599--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 2001.

Reports Available

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

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

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

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

14. Lectures by the Staff Outside the Department

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

Åkesson, Johan

Safe Manual Control of the Furuta Pendulum, University of California, San Diego, USA, August 27.

Safe Manual Control of the Furuta Pendulum, Conference on Control Applications, Mexico City, Mexico, September 6.

Åström, Karl Johan

Friction Models and Friction Compensation, Coordindated Science Laboratory, University of Illinois at Urbana-Champaign, USA, January 23.

Modeling of Physical Systems, Coordinated Science Laboratory, University of Illinois at Urbana-Champaign, USA, January 30.

Drum Boiler Dynamics, Department of Mechanical Engineering, University of Illinois at Urbana-Champaign, USA, February 8.

Using Bicycles to Illustrate Limitations in Control System Design, Coordinated Science Laboratory, University of Illinois at Urbana-Champaign, USA, February 13.

Control - The Hidden Technology, Coordinated Science Laboratory, University of Illinois at Urbana Champaign, USA, February 19.

Stabilization of Unstable Systems, University at Pavia, Italy, March 28.

Tools for Modeling of Physical Systems, University of Pavia, Italy, April 4.

Control - The Hidden Technology, Politecnico di Milano, Italy, April 6.

Friction Models and Friction Compensation, University of Pavia, Italy, April 26.

Fundamental Limitations in Control Design, Politecnico di Milano, Italy, April 27.

Control - The Hidden Technology, University of Pavia, Italy, May 2.

Modeling of Complex Systems, Symposium on Complex Systems Modeling and Optimization, Harvard University, USA, June 23.

Grey Box Modeling of a Steam Generator, The Bohlin Symposium, KTH, Stockholm, Sweden, August 24.

Fundamental Limitations on Control Design, École des Mines de Paris, Fontainebleau, France, September 10.

Manual Control of Unstable Systems, École Supérieure d'Electricité, Paris, France, September 11.

Modeling of Physical Systems, Dept of Mechanical and Environmental Engineering, University of California, Santa Barbara, USA, November 26.

Årzén, Karl-Erik

Simple Feedback Control and Mode Switching Strategies for GDI Engines, Ecole des Mines, Nantex, France, January 18.

Cervin, Anton

Analyzing the Effects of Missed Deadlines in Control Systems, ARTES Graduate Student Conference, Lund, Sweden, March 8.

Analysis and Simulation of Control Loop Timing, Department of EECS, University of California at Berkeley, USA, September 25.

Distributed Wireless Control Using Bluetooth, Department of ME, University of California at Berkeley, USA, September 27.

Simulation and Analysis of Control Loop Timing, Department of EE, University of Illinois at Urbana-Champaign,, USA, October 2.

Simulation and Analysis of Control Loop Timing, Department of CS, University of Illinois at Urbana-Champaign, USA, October 2.

Design and Simulation of Heterogeneous Control Systems Using Ptolemy II, IFAC Conference on New Technologies for Computer Control, Hong Kong, P.R. China, November 19.

Distributed Wireless Control Using Bluetooth, IFAC Conference on New Technologies for Computer Control, Hong Kong, P.R. China, November 20.

Integrated Control and Scheduling, "Västsvensk fordons- och forskningsdag" (seminar day organized by ARTES and Volvo Car Corporation), Göteborg, Sweden, December 12.

de Maré, Lena

Process Control, Invited lecture at SBL Vaccin, Solna, Sweden, June 1.

Probing Control of Glucose Feeding, Invited lecture at SBL Vaccin, Solna, Sweden, June 1.

Eborn, Jonas

ThermoFluid–Modelica and the Thermo-Hydraulic Base Library, Invited lecture at LiTH, Linköping, Sweden, May 3.

ThermoFluid - Physical Modeling with Modelica and the Thermo-Hydraulic Base Library, Invited lecture at KTH, Stockholm, Sweden, May 17.

Gäfvert, Magnus

Control of Gasoline Direct Injection Engines using Torque Feedback, NACO2 Workshop on Automotive Control, Dept. of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 19.

Presentation of DICOSMOS2, Seminar at Volvo TU, Gothenburg, Sweden, December 7.

Grundelius, Mattias

Optimal Control of Liquid Slosh, Centre Automatique et Systemes, Ecole des Mines de Paris, Fontainebleau, France, May 28.

Iterative Learning Control of Liquid Slosh, Centre Automatique et Systemes, Ecole des Mines de Paris, Paris, France, May 30.

Gulchak, Andrey

Controlled Dynamical Systems, Lecture at the Department of Mathematics, Lund University, December 11.

Dual Problem in Multi-Objective H^p Control, Presentation at the European Control Conference, Porto, Portugal, September 4–7.

Duality in Robust Control: Controller vs. Uncertainty,, Presentation at the 40th IEEE Conference on Decision and Control, Orlando, USA, December 4–7.

Hagander, Per

Kvinnligt och Manligt. Att undervisa kvinnliga teknologer, lecture at LTH – course “Pedagogical Inspiration”, October 10.

Kamratgranskning, Project presentation at LTH – course “Pedagogical Inspiration”, October 24.

Hägglund, Tore

Process Control in Practice, Industrial course. Stockholm, Sweden, January 24–25.

Automatic Supervision of Control Loops, Invited lecure. Sydkraft – Process Control Seminar, Malmö, Sweden, March 22.

Från Alarmering till Adaptering (From Adaptation to Detection), Invited lecture. NPI Seminar. Mid Sweden University, Örnsköldsvik, Sweden, May 9.

Process Control in Practice, Folkuniversitetet, Lund, Sweden, May 29.

Hedlund, Sven

Optimal Control of Hybrid Systems Via Convex Dynamic Programming, Faculty of Information Technology & Systems, Delft University of Technology, The Netherlands, February 12.

Optimal Control of Hybrid Systems Via Convex Dynamic Programming, Department of Electrical Engineering, Eindhoven University of Technology, The Netherlands, February 26.

Optimal Control of Hybrid Systems Via Convex Dynamic Programming, Centrum voor Wiskunde en Informatica, Amsterdam, The Netherlands, February 27.

Henriksson, Dan

Simulation of Feedback Scheduling, LUCAS Seminar Day, Lund, Sweden, October 22.

Johansson, Rolf

Postural Control, Annual Symp. of Icelandic Medical Association-Læknadaga 2001, Reykjavik, Iceland, January 18.

System Identification of Continuous-Time Models, IEEE Lecture, University of Iceland, Reykjavik, Iceland, January 19.

Adaptive Control—Introduction, The Dynamical Systems Group (DSG), Dept. Mech. Eng., Dept. Elec. Comp. Eng., Rice University, Houston, TX, May 7.

Adaptive Control—Real-Time Parameter Estimation, The Dynamical Systems Group (DSG), Dept. Mech. Eng., Dept. Elec. Comp. Eng., Rice University, Houston, TX, May 7.

Adaptive Control—Self-Tuning Control, The Dynamical Systems Group (DSG), Dept. Mech. Eng., Dept. Elec. Comp. Eng., Rice University, Houston, TX, May 8.

Adaptive Control—Model Reference Adaptive Systems, The Dynamical Systems Group (DSG), Dept. Mech. Eng., Dept. Elec. Comp. Eng., Rice University, Houston, TX, May 8.

Adaptive Control—Stability Analysis & Convergence, Input-Output Stability, The Dynamical Systems Group (DSG), Dept. Mech. Eng., Dept. Elec. Comp. Eng., Rice University, Houston, TX, May 9.

Adaptive Control—Adaptive System Analysis-Averaging, Robustness, The Dynamical Systems Group (DSG), Dept. Mech. Eng., Dept. Elec. Comp. Eng., Rice University, Houston, TX, May 9.

Adaptive Control—Automatic Tuning & Gain Scheduling, The Dynamical Systems Group (DSG), Dept. Mech. Eng., Dept. Elec. Comp. Eng., Rice University, Houston, TX, May 10.

Adaptive Control—Implementation , Case Studies & Products, The Dynamical Systems Group (DSG), Dept. Mech. Eng., Dept. Elec. Comp. Eng., Rice University, Houston, TX, May 10.

Postural Control, Universidad de Valladolid, Valladolid, Spain, May 30.

State-space System Identification, Universidad de Valladolid, Valladolid, Spain, May 30.

State-space System Identification, CDS Seminar, CalTech, Pasadena, CA, June 13.

Postural Control, University of Southern California, Dept. Electrical Engineering, June 18.

Observer-Based Strict Positive Real Feedback Control System Design, Norwegian University of Science and Technology (NTNU), Trondheim, Norway, August 14.

Adaptive Cruise Control, Norwegian University of Science and Technology (NTNU), Trondheim, Norway, August 15.

Postural Control, Norwegian University of Science and Technology (NTNU), Trondheim, Norway, August 22.

Sensor-data Integration, Nutek/Vinnova Program Conference, Västerås, September 3.

Identification géométrique et dynamique—State-space system identification, IFMA, Clermont-Ferrand, France, November 22.

Matematik i bild och rörelse—Reglering av robotar, Kulturen, Lund, October 4.

Identification of Adaptation in Human Postural Control using GARCH Models, IEEE Conf. Decision and Control (CDC 2001),Orlando, FL December 4.

System Identification Applied to Spatial and Temporal Propagation of Atrial Activity During Atrial Fibrillation, IEEE Conf. Decision and Control (CDC 2001), Orlando, FL December 4.

Model-Based Estimation of Cylinder Pressure Sensor Offset using Least-Squares Methods, IEEE Conf. Decision and Control (CDC 2001), Orlando, FL December 6.

Subspace-Model Identification of Continuous-Time Models, Department of Systems Science & Mathematics, Washington University, Saint Louis, MO, December 11.

Lincoln, Bo

Optimizing linear system switching, Conference of Decision and Control, Orlando, Florida, USA, December 5.

Control over networks., Dept. of Control and Dynamical Systems, Caltech, Pasadena California, USA, September 10.

Control over networks., Coordinated Science Laboratory, University of Illinois, Champaign, Illinois, USA, September 27.

Petersson, Mikael

Assessing Measurements for Feedforward Control, Invited lecture at Division of Automatic Control, Linköping University, Sweden, June 7.

Rantzer, Anders

Density and flow: A different view on nonlinear control, Seminar at Eindhoven University of Technology, Eindhoven, The Netherlands, February 7.

Density and flow: A different view on nonlinear control, Plenary lecture at 20th Benelux Meeting on Systems and Control, Houffalize, Belgium, March 28.

Density and flow: A different view on nonlinear control, Plenary lecture at 4th Russian-Swedish Control Conference, Moscow, Russia, May 14.

Density and flow: A different view on nonlinear control, Seminar at University of Illinois at Urbana-Champaign, Urbana, USA, May 24.

Density and flow: A different view on nonlinear control, Seminar at University of Illinois at Urbana-Champaign, Urbana, USA, May 30.

Density and flow: A different view on nonlinear control, Seminar at University of California at Santa Barbara, Santa Barbara, USA, June 4.

ABS Control by Gain Scheduling, Workshop on Hybrid Control Applications Organized by DaimlerChrysler, Berlin, June 7.

Reduction and Aggregation of Process Models, Project meeting in Center for Chemical Process Design and Control, Tylösand, August 29.

Smooth blending of nonlinear controllers using density functions, European Control Conference, Porto, Portugal, September 6.

Duality in Robust Control: Uncertainty versus Controller, 40th IEEE Conference on Decision and Control, Orlando, USA, December 4.

Almost global stability of phase-locked loops, 40th IEEE Conference on Decision and Control, Orlando, USA, December 4.

Density and flow: A different view on nonlinear control, Seminar at University of Minnesota, Minneapolis, USA, December 10.

Density and flow: A different view on nonlinear control, Massachusetts Institute of Technology, Cambridge, USA, December 13.

Robertsson, Anders

Observer-Based (SPR) Feedback Control System Design, 5th IFAC Nonlinear Control Systems Design Symposium, St. Petersburg, Russia, July.

Observer-Based Impedance Control in Robotics, 5th IFAC Nonlinear Control Systems Design Symposium, St. Petersburg, Russia, July.

Observer-Based Control for a Class of Nonlinear Systems, 4th Russian-Swedish Control Conference, Moscow, Russia, May 15.

Sandberg, Henrik

An upper error bound for model reduction of linear time-variable systems, Seminar on Control and Dynamical Systems, Caltech, Pasadena, USA, March 21.

Periodic Modelling of Power Systems, Seminar on Computational Science and Engineering, UC Santa Barbara, USA, May 8.

Periodic Modelling of Power Systems, Second Southern California Nonlinear Control Workshop, UC San Diego, USA, June 2.

Periodic Modelling of Power Systems, IFAC Workshop on Periodic Systems and Control, Cernobbio-Como, Italy, August 27.

Slätteke, Ola

Control of the Drying Section of a Paper Machine, Industrial Course at Korsnäs AB, Gävle, Sweden, May 15.

Control of the Drying Section of a Paper Machine, Invited lecture at Stora Enso Fors AB, Fors, Sweden, October 23.

Tummescheit, Hubertus

Physical System Modeling with Modelica: Overview Seminar and Course, Seminar and 2-Day Course at United Technologies Research Lab, Hartford, CT, USA, January 25–26.

Modeling of Fuel Cell Systems with the ThermoFluid Library, Course at United Technologies Research Lab, Hartford, CT, USA, January 29.

Power Plant Modeling with Modelica and the ThermoFluid Library, Seminar at ABB Corporate Research Center, Heidelberg, Germany, March 23.

Modeling of Complex Physical Systems with Modelica, Seminar at Frauenhofer Institut Solare Energiesysteme, Freiburg, Germany, May 9.

Modeling of Complex Physical Systems with Modelica, Seminar at Systems and Control Group, Eindhoven Technical University, Eindhoven, The Netherlands, May 13.

Modeling of Process Systems with Modelica, Seminar at Department of Chemical Engineering, University of Dortmund, Germany, November 15.

Modeling Combustion and Acoustics with Modelica and the ThermoFluid Library, Seminar at MathCore AB, Linköping, Sweden, December 3.

Wittenmark, Björn

Sample-Induced Delays in Synchronous Multirate Systems, European Control Conference, Porto, Portugal, September 7.

Sample-Induced Delays in Synchronous Multirate Systems, University of Melbourne, Australia, October 25.

Sample-Induced Delays in Synchronous Multirate Systems, University of New South Wales, Sydney, Australia, November 6.

Adaptive Extremal Control, University of Melbourne, Australia, November 22.

15. Seminars at the Department

Seminars presented in order of date. The seminars were given at the department during 2001, 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 18: **Anders Hansson** (KTH), *Efficient Solution of Semidefinite Programs for Integral Quadratic Constraints.*

Jan 18: **Andreas Hörjel** (LTH), *Bluetooth in Control.* MSc-thesis presentation.

Jan 25: **Francesca Ceragioli** (Politecnico di Torino, Italy), *Nonlinear Systems, Discontinuous Feedbacks and Nonsmooth Lyapunov Functions.*

Jan 25: **Telina Englund, Helene Fridman** (LTH), *Medical Image Registration.* MSc-thesis presentation.

Feb 6: **International Project Course**, *Vehicle Dynamics Control.*

Feb 26: **John W. Perram**(SDU-Odense University and Latrobe University), *The Pendulum–New Physics.*

Feb 27: **Pia Eklund, Marianne Tufvesson** (LTH), *Predictive Control of Irrigation Channels.* MSc-thesis presentation.

March 1: **Philip Thomas** (City University, London), *The Time-Domain Distortion Method of Model Validation.*

March 1: **Heinz A. Preisig** (TU Eindhoven), *Modelling-Art or Science?–Games with Timescales.*

March 2: **Jonas Eborn** (AC), *On Model Libraries for Thermo-Hydraulic Applications.* Doctoral dissertation defence.

March 16: **Naomi Leonard** (Princeton University), *Schooling Autonomous Vehicles with Artificial Potentials.*

March 19: **Anders Göransson** (LTH), *Active Control of Combustion Instabilities.* MSc-thesis presentation.

March 20: **Leo Siang Kwong** (National University of Singapore), *Automatic Test System for Network Servers.* MSc-thesis presentation.

March 21: **Anders Rantzer** (AC), *Density and Flow: A Different View on Nonlinear Control.*

March 21: **Lars Wallén** (LTH), *Adaptive Slip Control.* MSc-thesis presentation.

March 28: **Alf Isaksson** (KTH), *Introduction to Grey-box Modelling.*

March 29: **Fredrik Holmberg** (LTH), *Implementation of a PID Controller for Building Automation.* MSc-thesis presentation.

April 2: **Susana Santos** (Universidad de Valladolid), *Systems Identification Applied to Cardiology.* MSc-thesis presentation.

April 4: **Zhiyong Geng** (Beijing University), *Robust Stability of the Systems with Parametric and Dynamic Uncertainties.*

April 5: **Gianfranco Rizzo**, *On Automotive Engine Modeling and Control.*

April 6: **Per Tunestål** (LTH), *Estimation of the In-Cylinder AirFuel Ratio of an Internal Combustion Engine by the Use of Pressure Sensors.* Doctoral dissertation defence.

April 10: **Emil Naef** (LTH), *Hard Real-Time and Synchronous Programming with SDL.* MSc-thesis presentation.

April 10: **Anton Shiriaev**, *Some Stabilization Problems for Underactuated Nonlinear Systems.*

April 24: **Wael Chatila** (LTH), *Producing Periodic Motion for Underactuated Systems.* MSc-thesis presentation.

April 25: **Johan Bengtsson** (AC), *Adaptive Cruise Control.*

April 26: **Antonio Gomez** (Universidad Politecnica de Cartagena, Spain), *Modeling of a Gas Turbine.* MSc-thesis presentation.

May 2: **Ralf Bachmayer**, *Advances in Nonlinear Dynamical Modeling and Control of Marine Thrusters: Theory and Experiment.*

May 11: **Knut Åkesson** (CTH), *Formella metoder och styrning av händelsebaserade system.*

May 22: **Eric Rohrbach**, *Fuel Cell Dynamic Modeling.*

May 23: **Luis Bento, Duarte Mendonca** (Universidade de Coimbra), *Robot Vision.* MSc-thesis presentation.

June 7: **Pericles Barros** (Universidade Federal de Paraiba, Brazil), *Relay Based Transfer Function Frequency Response Estimation.*

June 27: **Domenico Scalamogna** (Universita degli studi di Firenze), *Iterative Learning Control with Application to Robotics.* MSc-thesis presentation.

June 29: **Kazuhiko Terashima** (Toyohashi University of Technology), *Motion Control of Automatic Pouring Robot by Hybrid Shaped Approach.*

Aug 8: **Abdulla Ismail** (United Arab Emirates University), *Control of Thermal Desalination Plants.*

Aug 14: **Alexander Megretski** (MIT), *Model Order Reduction Using Maximal Real Part Norms.*

Aug 15: **Johan Åkesson** (AC), *Safe Manual Control of the Furuta Pendulum.*

Aug 20: **Henrik Sandberg** (AC), *Periodic Modelling of Power Systems.*

Sep 6: **Per Johansson** (LTH), *An Adaptive PPI-Controller.* MSc-thesis presentation.

Sep 17: **Michail Bourmpos** (Imperial College), *Robustness to Varying Timedelay in Visual Servoing Control.* MSc-thesis presentation.

Sep 25: **Andrej Barabanov** (St. Petersburg State University), *H-infinity Control of Delayed Systems.*

Sep 28: **Magnus Hjerpe** (LTH), *Analysis of Body Kinematics and Force Modulation.* MSc-thesis presentation.

Oct 10: **Tomas Olsson** (LTH), *Vision Guided Force Control in Robotics.* MSc-thesis presentation.

Oct 25: **Pierre Rouchon** (Ecole des Mines de Paris), *Dynamics and Solutions to Some Control Problems for Water-tank Systems.*

Oct 26: **Mattias Grundelius** (AC), *Methods for Control of Liquid Slosh.* Doctoral dissertation defence.

Nov 14: **Jonas Ludvigsson, Andreas Ekstrand** (LTH), *Generic Web Server in Embedded Control Systems.* MSc-thesis presentation.

Nov 19: **Markus Öberg** (LTH), *Optimizing Operation Times in a Storage Control System.* MSc-thesis presentation.

Nov 21: **Xavier Bombois** (Delft University of Technology), *Connecting Prediction Error Identification and Robust Control Analysis: a New Framework.*

Nov 30: **Johan Bengtsson** (AC), *Adaptive Cruise Control and Driver Modeling.* Lic Tech dissertation seminar.

Dec 12: **Gert-Ola Carlsson** (LTH), *Statecharts in ABB Control-IT.* MSc-thesis presentation.

Dec 18: **Lars Rundqwist** (Saab), *Mission Systems for Helicopters.*