Activity Report: Automatic Control 1994-1995

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Activity Report

Automatic Control

1994–1995

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Contents

1. Introduction

This report covers the activities at the Department of Automatic Control at Lund Institute of Technology (LTH) during the period 1 July 1994 – 30 June 1995, which is the academic year 1994/95. The budget for the year was 21 MSEK including rent for offices and laboratories.

During this period 3 PhD theses were completed by Per-Olof Källén, Mats Andersson, and Anders Hansson. This brings the total number of PhDs graduating from our department to 44. Per-Olof and Mats are now working for Volvo and Anders has a post doc at Stanford University. 24 students completed their MSc degree at the department. Two books, *Adaptive Control* and *PID Controllers: Theory, Design, and Tuning*, 17 journal papers or book chapters, and 24 conference papers were published by staff members.

720 students graduated from seven courses in the civ.ing. program. There was a very high activity in the control laboratory with 234 groups of experiments. 6 PhD courses were given during the academic year.

Research has continued in established areas such as adaptive and robust control, computer-aided control engineering, applications such as robotics, and power systems.

Among the highlights of the year was a renewal of our Multi-Project Grant from TFR. This program is the core long-term financing of our group. The external reviews were very favorable. In particular it was emphasized that we had been able to combine our traditions with new approaches.

Other highlights were the organization of an IFAC Workshop and the beginning of a collaboration beetween the universitites in Lund and Copenhagen. In August 1994 we also experienced a very remarkable flight ... All this is described below.

The rest of the report is organized as follows. Economy and facilities are presented in Chapter 2, the educational activity is described in

Chapter 3, and the research projects in Chapter 4. The research staff and their activities are presented in Chapter 5. Our retrospect this year is about the results of our graduate program. This is given in Chapter 6. Abstracts of the PhD dissertations completed this year are given in Chapter 7. In Chapters 8–13 you find detailed information about awards, staff and guests, publications, lectures, and seminars.

An International Workshop

The 2nd IFAC Workshop on Computer Software Structures Integrating AI/KBS Systems in Process Control was organized in August 1994 with Docent Karl-Erik Årzén as the Chairman of the International Program Committee and the National Organizing Committee.

The workshop was sponsored by the IFAC Technical Committee on Applications, Working Group on Chemical Process Control with IFAC Technical Committee on Computers, IEEE Control Systems Society and Swedish AI Society as co-sponsors. The workshop was financially supported by the Swedish Research Council for Engineering Sciences (TFR), Lund Institute of technology, ABB and Gensym Corporation who also participated at the software exhibition in connection with the workshop.

The workshop attracted 88 participants of which 36 represented industry. Among the countries represented were Japan, Taiwan, South Africa, Canada, and USA. The sessions covered software integration, knowledge representation and modelling, operator support systems, monitoring and diagnosis, and control.

Lund-Lyngby Collaboration

There is a general agreement on collaboration between the Universities in Lund and Copenhagen. The initiative for the *Lund-Lyngby Day on Control* was taken by students from the Technical University of Denmark in Lyngby (DTU) and the Department of Automatic Control at LTH. The purpose of this meeting was to stimulate discussions and cooperation between the research groups at LTH and DTU that are active in systems and control. This involves researchers from the Institute of Automation, the Department of Mathematics, The Department of Chemical Engineering and the Institute for Mathematical Modelling at DTU. Another issue was that students should be responsible for the planning and organization.

The first Lund-Lyngby Day on Control was held in Lund at May 26. There were 22 participants of which 11 were from DTU. A total of 15 seminars were given during the meeting. A second Lund-Lyngby day will take place at DTU during fall 1995.

European Collaboration

We are participating in the following European projects:

- HCM – EURACO – European Network for Robust and Adaptive Control under the EU Human Capital and Mobility network.
- HCM –Nonlinear and Adaptive Control under the EU Human Capital and Mobility network.
- FALCON – Fuzzy Algorithms for control. Basic Research Working Group 6017. This collaboration was started before Sweden joined the EU.
- ESPRIT – Tools for the Analysis of Hybrid Systems.

The number of students from Europe in Erasmus and other European programs continues to increase. During this academic year we had 6 students in these programs.

Acknowledgements

We want to thank our sponsors, Swedish National Board for Industrial and Technical Development (NUTEK), Swedish Research Council for Engineering Sciences (TFR), Swedish Natural Science Research Council (NFR), Swedish Council for Planning and Coordination of Research (FRN), Swedish Medical Research Council (MFR), Sydkraft AB, Swedish Institute of Applied Mathematics (ITM), Bo Rydin Foundation, and ABB for their support to our projects.

Karl J. Åström Taken for a Ride!

To celebrate Karl's 60th birthday, in August 1994, he was kidnapped by the department. The goal of the excursion was the airforce base F10 in Ängelholm. A group of about 90 people, consisting of former and present members of the department and their families, took part in the celebrations.

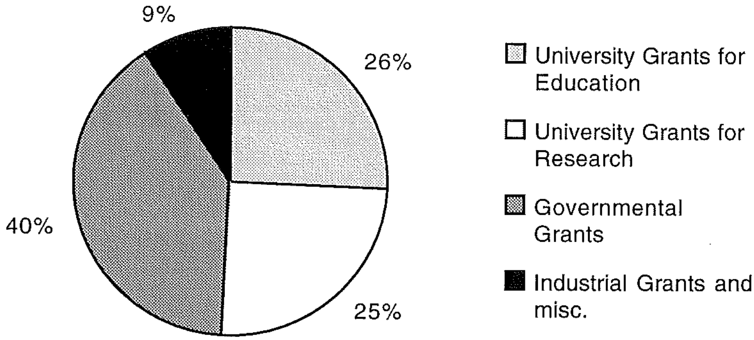
Under the supervision of the experienced flight engineer Hans Rosén (a former MSc student) Karl flew over Skåne in an SK60.

Karl's comment afterwards was: "It was like controlling a double integrator."

2. Economy and Facilities

Economy

The income for the academic year 1994/95 was 21.0 MSEK, with the following distribution:



Facilities

The main facilites are laboratories and computer systems. Our main computing resource is a network of Unix workstation. All members of the department have workstations on their desks that are connected to this network. The system was upgraded during this academic year with funding provided by TFR.

The teaching laboratories are based on desktop processes and personal computers. The 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. The processes that are used most frequently are tank systems, servos, and ball and beam systems. These have all been developed at the department. During this year we started development of an inverted pendulum of the TIT configuration. We also acquired a helicopter model from ETH. The computers were also upgraded. All computer systems are now linked via Ethernet. This simplifies the operation of the teaching labs significantly.

For more elaborate experiments, e.g. the robotics experiments, we use VME systems which are linked to the Ethernet. During this academic year the robots were provided with six degree of freedom force sensors.

A substantial effort was also devoted to the software used for real time control. We have now a unified software environment for Sun, VME and PCs based on Modula 2, C and C++. Work is under way to improve our real time kernel so that the same kernel can be used on all systems.

Skrivas i 1995/96:

We have started to improve the software used in the teaching lab. In particular we aim to obtain man-machine interfaces that are state-of-the art. In connection with this we are also porting the real time kernel that has been developed in house to Windows NT.

3. 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 is equivalent 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 Enginering (M), and Chemical Engineering (K). During 1994/95 the following courses were given at the department:

Course	**Number of graduated students**
Reglerteknik AK–FED *FRT010* (Automatic Control, basic course)	283
Reglerteknik AK–M *FRT060* (Automatic Control, basic course)	112
Processreglering (K) *FRT080* (Automatic Process Control)	108
Digital Reglering (FED) *FRT020* (Computer-Controlled Systems)	62
Realtidsystem (FED) *FRT031* (Real-Time Systems)	49
Processidentifiering (FED) *FRT040* (Process Identification)	28
Adaptiv reglering (FED) *FRT050* (Adaptive Control)	32
Olinjär reglering och Servosystem (FED) *FRT075* (Nonlinear Control and Servo Systems)	22

A total of 720 students have passed our courses. This corresponds to 82 full year equivalents.

The control laboratory has been used extensively during the year. Simple fixed experiments are done in the basic courses. In the courses on adaptive control and system identification there are also open ended experiments. In the basic courses we can have up to eight parallel experiments for one group, and in the elective courses we have four in parallel. There were 234 groups of students that made four-hour laboratories at the department. To handle this many groups there are many experiments in the evenings.

Master's Theses

Twentyfour students completed their master theses during the year. The theses concerned the following areas: Adaptive control (1), Control design (1), Computer-aided control engineering (2), Discrete-events systems and Petri nets (1), Fuzzy control (1), Neural networks (3) Nonlinear systems (4), Power systems (1), Process control (4), Real-time systems (1), Robotics and servo systems (3), System identification (1), Vehicle dynamics (1).

A complete list of the theses is given in Chapter 11.

Doctorate Program

Three PhD theses were completed during the period: Per-Olof Källén (1994), Mats Andersson (1995), and Anders Hansson (1995). The abstracts are given in Chapter 7. This brings the total number of PhDs graduating from our department to 44. Five new PhD students (Jonas Eborn, Johan Eker, Erik Gustafson, Mikael Johansson, Mats Åkesson) were admitted.

The following PhD courses were given:

- Introduction to Robust and Adaptive Control (B. Bernhardsson) 2 points
- Introduction to ℓ_1 Robust Control (M. Dahleh) 2 points
- Behavioral Models of Dynamical Systems (J. Willems) 2 points

- Linear Quadratic Control Theory (B. Bernhardsson) 5 points
- Linear Systems 1 (A. Rantzer) 5 points
- Linear Systems 2 (A. Rantzer) 5 points

The department has recently taken the initiative to create a graduate program in Systems and Applied Mathematics at Lund Institute of Technology. The program is a cooperation between the departments of Mathematics, Mathematical statistics, Automatic control, Telecommunication theory, Communications systems, Information theory, and Computer sciences. The goal with this program is to coordinate and develop the graduate courses within the area of systems and applied mathematics. In the "Linear Systems 1" course there were several students from other departments, especially from the Department of Information Theory.

4. Research

The goal of the department is to provide students with a solid theoretical foundation combined with a good engineering ability. This is reflected in the research program which broadly speaking is divided into theory and applications. The roles of the universities in technology transfer has recently been emphasized in Swedish research policy as the "the third task."

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.

The major research areas are:

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

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

Tuning, Adaptation, and Robust Control

Research on adaptive control was for a long time focused on control of linear systems with unknown or slowly drifting parameters. Feedback from applications indicated that there was a substantial industrial need to develop tuners for simple controllers of the PID type. Traditional adaptive control is maturing in the sense that many problems have been solved. In our judgement it is important to maintain a high level of competency in the field – particularly for the reason of technology transfer – but we are also pursuing new research directions. One approach is adaptive control of nonlinear systems, another is the relation between adaptive and robust control, which also gives a natural way to deal with systems with gain scheduling. A fundamental problem in the area is to obtain a better understanding of the classes of system where robust and adaptive control is most appropriate.

Applications of automatic tuning and adaptive control have inspired work in integrated control and diagnosis. This has a direct coupling to safety networks for adaptive controllers. Building on earlier work on expert control and some industrial applications we have embarked upon several problems in this direction. Some of the specific projects are listed below.

Frequency Domain Adaptive Control

Researchers: Per-Olof Källén, Björn Wittenmark and Karl Johan Åström

In this project we analyze an adaptive control scheme that is based on a frequency domain system description. It has been shown that the proposed scheme has several good properties. The project is reported in the PhD thesis by Per-Olof Källén.

The main goals of the work have been to analyze the estimation and the design procedures as well as the interaction between the two parts. One advantage of the proposed method is that the frequency response estimates are decoupled in the frequency domain, which will decrease

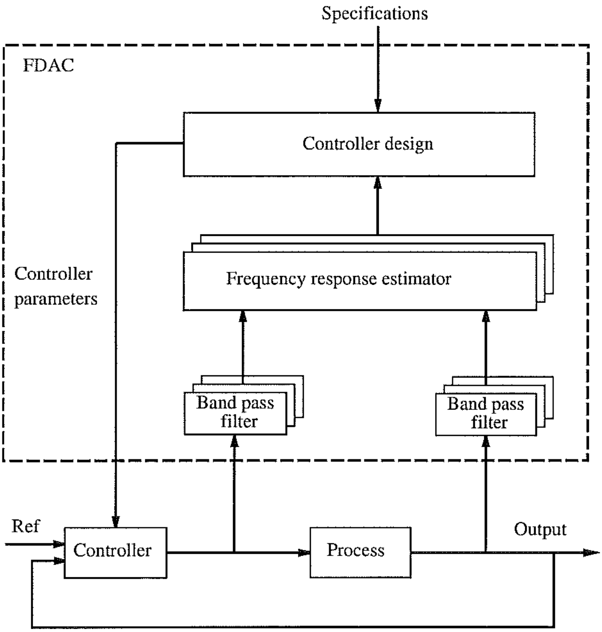


Figure 4.1 Block diagram of an adaptive controller based on the frequency domain approach. A simple version of this controller is used in a product family for Alfa Laval Automation.

the interplay between the estimation and the design.

The process is modeled by a number of points on the Nyquist curve. These points are estimated using low order parametric models based on band pass filtered data. The properties of the frequency response estimators have been analyzed with respect to convergence and parameter sensitivity. The choice of the band pass filters is a trade-off between estimation accuracy and adaptation speed. This has been analyzed and resulted in some guidelines for the choice of band pass filters.

The design method can be considered as an approximation method and is primarily used for designing low order controllers. The basic design method has been modified to improve the robustness of the closed loop system. Connections to the polynomial pole placement design have also been established. The desired closed-loop bandwidth is a crucial parameter in the design method. Guidelines have been determined for how to choose the structure of the desired closed-loop response. To improve the applicability of the design method it is possible to incorporate a procedure that automatically chooses the appropriate closed-loop bandwidth. With bandwidth adaptation it is not necessary to choose a desired bandwidth a priori, and further, it also gives closed-loop specifications that adapt to changing process dynamics. A startup procedure has been developed, which makes it easier to use the adaptive controller. This startup procedure can to a large degree be automated.

Adaptive Control of Systems with Friction, Hysteresis and Backlash

Researchers: Henrik Olsson and Karl Johan Åström

The new friction model developed in collaboration with Laboratoire d'Automatique de Grenoble has been published. The model is simple yet it captures many of the friction properties observed in real systems. During the year further refinements of the model have been done.

The effect of friction on limit cycles in control systems has been explored. Different techniques to analyze and predict such limit cycles and to determine their dependency on friction properties have been investigated. A detailed model of an industrial control loop with a valve

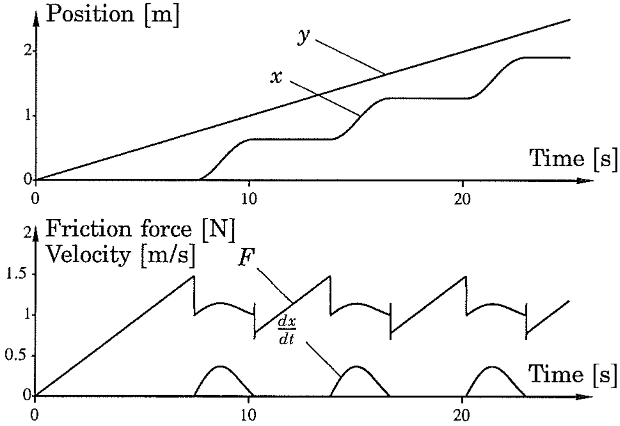


Figure 4.2 Simulation of stick-slip motion with the new model.

with friction has also been developed. The behavior of the model agrees with real data.

Research has also been initiated on adaptive control of systems with simple nonlinearities such as dead-zones and backlash.

In this project we have made good use of the possibilities to interact with other universities in the Human Capital and Mobility Network on *Nonlinear and Adaptive Control.*

Control of Uncertain Systems

Researchers: Anders Rantzer, Bo Bernhardsson, Ulf Jönsson, Lennart Andersson and Per Hagander

This project is devoted to analysis of system models consisting of a linear time-invariant nominal model and perturbations due to nonlinearities, uncertain dynamics or time-variations.

The main tool for analysis is the concept Integral Quadratic Constraints (IQC's), introduced by Yakubovich in the 70's. Based on this, a general strategy for system analysis has been developed in cooperation with prof. Megretski, USA. First, the model perturbations are described

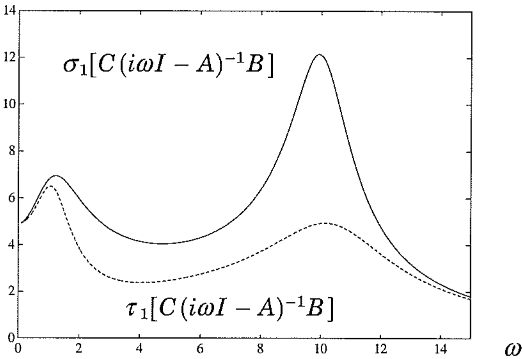


Figure 4.3 Plot of largest singular value and perturbation value of a system.

as accurately as possible by IQC's, then these constraints are used to quantitatively analyze the effects of the system perturbations. Computationally, the analysis takes the form of convex optimization in terms of linear matrix inequalities.

For parametric uncertainty the above strategy is equivalent to so called μ-analysis. However, to improve the reliability of the results, it is often desirable to take time-variations into account in the analysis. An important step of the project has therefore been to generate and apply new IQC's in the case of time-varying uncertain parameters with bounded derivatives.

Also static nonlinearities, like saturations, dead-zones and friction have been studied in a similar fashion. In particular, the trade-off between controller gain and allowable measurement delay has been studied in detail for a feedback system with saturation.

Duality theory for convex optimization has turned out to be instrumental to generate bounds and insight on the fundamental limitations of the analysis method. In particular, attractive duals have been found in the context of μ-analysis and its time-varying counterparts.

The work on the so called real perturbation values has also continued.

Several other groups around the world are now looking on different aspects of the problem, such as convergence rate for numerical algorithms, continuity aspects and connections with other parts of mathematics and system theory. We have continued the collaboration with Professor Qiu from Hong Kong University. Our proof of the formula for τ_k was presented at the Hurwitz Centennial in Ascona in May 1995 and our Automatica article for the τ_1-case was published in June 1995. The main goal is now to find new applications of the real perturbation values and to better understand their relation to other uncertainty measures.

Relay Feedback

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

Relay feedback is a key ingredient in automatic tuning and initialization of adaptive controllers. It has been successfully used in many industrial applications. A relay feedback system is also one of the simplest examples of switched or hybrid systems. There are several fundamental problems in relay feedback that are not fully understood. One of them is the problem of characterizing all linear systems that give a unique stable limit cycle under relay feedback. A new method for analyzing global attraction to a limit cycle is under development. Some low order systems have been characterized using this method.

Hybrid Systems

Researchers: Jörgen Malmborg, Bo Bernhardsson and Karl Johan Åström

Hybrid systems is an active research area on the border between Computer Science and Automatic Control. A typical hybrid system consists of a physical process under control and supervision of a discrete computer. Physical systems may show behavior that is convenient to model as discrete events. Examples are mechanical systems with backlash, dead zones, and static friction, or electrical systems with switches. A valve in a process model may become stuck because of high friction. Switching between the two states "stuck" and "moving" are discrete events. Whether a physical phenomenon is modeled as a continuous evolution or a discrete event, depends on the desired level of detail in the model, and its relative time scale, compared to other interesting phenomena in the system. It may also be advantageous to use control strategies with switching in cases where there are no mode changes in the process. In this project it is attempted to use switching strategies to improve the performance of simple controllers and facilitate controller design.

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

Automatic Tuning of PID Controllers

Researchers: Tore Hägglund and Karl Johan Åström

This project has been in progress for over ten years, and resulted in industrial products as well as several PhD thesis. During the academic year 1994/95, a new monograph on PID control that is based on experiences obtained in the project has been published, see Åström and Hägglund (1995) in Chapter 10. New significant insight into the problem of what information that is required to tune PID controllers has

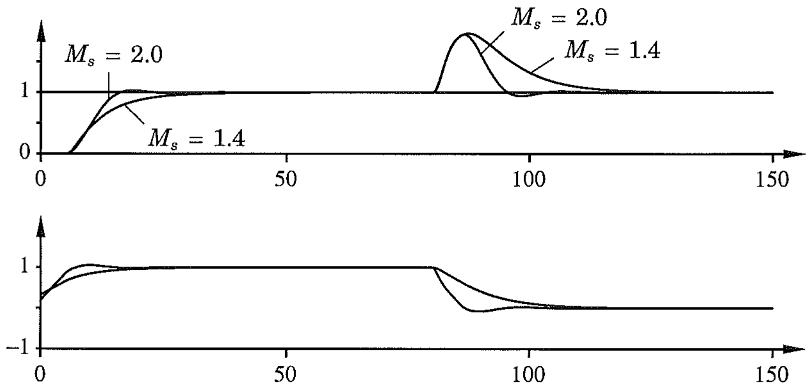


Figure 4.4 Measurement signal (upper diagram) and control signal (lower diagram) after setpoint and load disturbances, with the controller tuned according to the new tuning methods.

been obtained. This has led to new simple design methods for PID controller tuning. The methods are immediately useful for both manual and automatic tuning. Some results have been transferred to Beijer Electronics AB in Malmö in connection with a master thesis project. There are, however, more opportunities for technology transfer.

Autonomous Control

Researchers: Karl Johan Åström, Tore Hägglund, Anders Wallén, Johan Eker, and Karl-Erik Årzén

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

The autonomous controller contains a wide range of algorithms and methods of quite different nature. It includes traditional real-time computations, sequential methods for loop assessment and tuning, and knowledge-based methods. Since all these methods must be put into the same framework, one obtains a typical hybrid system. We have experimented with different architectures. The use of extended Grafcet for structuring the control algorithms has been successful.

A toolbox for rapid prototyping of real-time applications has been developed. The language PAL (Pålsjö Algorithm Language) is used for describing real-time processes, which are compiled and downloaded to a VME-target computer. The run-time environment allows real-time configuration of the system. The toolbox currently runs on VME-computers but will also be available for Windows NT. The PAL-compiler also supports the GRAFCET-1131 standard.

A good collaboration with the pulp and paper industry has been established to get access to a number of realistic examples. A specific result of this work has been a new simple method for detection of friction-generated oscillations. One version has been implemented in the controllers manufactured by Alfa-Laval Automation.

Integrated Control and Diagnosis

Researchers: Karl-Erik Årzén

The goal of this project is development of methods for integrated design of control and supervisory functions, development of model-based diagnosis techniques, and implementational issues of on-line diagnosis systems. The focus over the last year has been control and diagnosis of sequential processes. The work on object-oriented extensions of the Grafcet sequential function chart formalism has continued. This has been combined with model-based diagnosis methods. It is currently applied to control and diagnosis of recipe-based batch productions systems. During the fall of 1994 a collaboration was initiated with Professor V. Venkatasubramanian of Purdue University. Two PhD students from Purdue, Raghu Rengaswamy and Dinkar Mylaraswamy, spent three months in Lund working on neural network based on-line diagnosis, comparisons of different diagnostics approaches, hybrid diagnosis and alarm filtering. During Spring 1995 Charlotta Johnsson and Anders Wallén visited Purdue where the work was continued.

Control of Critical Processes

Researchers: Anders Hansson, Per Hagander, and Lennart Andersson

Many processes in industry are critical. They are often critical in the sense that they have a limiting level. This can be either physical or artificial. Examples of the former are such levels that cannot be exceeded without catastrophic consequences, e.g. explosion. One example on the latter is alarm levels, which if they are exceeded will initiate emergency shutdown or a change in operational conditions. Another example is quality levels, which if they are not exceeded will cause unsatisfied customers. Common to the critical processes are that they enter their critical region abruptly as a signal exceeds a limiting level.

Initial results within the area of nonlinear feedback control were obtained in a master thesis project, and the work has continued. However, most results are within the area of linear feedback control. The so called Minimum Upcrossing (MU) controller, which minimizes the mean number of exceedances of the critical level, has been proposed as a solution to the problem. This has been compared with the well-known minimum variance controller with respect to different criteria capturing the control objectives described above. It has been shown that it is possible to compute the MU controller by making a one-dimensional optimization over LQG-problem solutions. The existence of the the MU controller has been investigated. To this end some research in the area of singular LQG problems has been done. This has furthermore motivated investigations of numerical routines for singular Riccati-equations.

System Identification

Researcher: Rolf Johansson

Research on several issues in system identification, especially modeling and identification of continuous-time systems, has been reported in the monograph *System Modeling and Identification* published in 1993.

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.

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

Computer Aided Control Engineering

This has been a major area of research at the department for a long time. It has the dual purpose of providing tools for making control engineering much more cost effective and being a glue between many different research projects. During this academic year the focus has been on development of tools for modeling and simulation of hybrid systems and development of model libraries for thermal power generation.

Modeling and Simulation of Complex Systems

Researchers: Sven Erik Mattsson, Mats Andersson, Bernt Nilsson, and Tomas Schönthal

The CACE project has for a number of years focused on devlopment of methods and computer tools which supports development and use of mathematical models. The results include an object-oriented modeling language called Omola and the interactive environment OmSim for development and simulation of Omola models. OmSim has been used in a couple of application projects in the areas of chemical processes and power systems (see below). It is a prototype environment and not a full-fledged professional and commercial product. The aim has been to develop and implement an environment which can be used in academia and industry for feasibility studies and as a basis for further research and commercial products. OmSim for Sun-4 workstations and HP workstations under the X Window System is available via anonymous FTP from URL: `ftp://ftp.control.lth.se/pub/cace`. It is implemented in C++ and uses only public domain software. Information is available also via WWW at URL: `http://www.control.lth.se/~cace`.

Combined Continuous and Discrete Event Models

Researchers: Mats Andersson and Sven Erik Mattsson

Modeling and simulation of Continuous Variable Dynamical Systems (CVDS) and Discrete Event Dynamical Systems (DEDS) have developed as two separate cultures. CVDS are typically natural, physical systems that obey the fundamental laws of matter and energy conservation. Their behaviors are described by differential and algebraic equations. DEDS are usually man-made systems like control, manufacturing and information systems. There is no uniform formalism for representing DEDS systems, comparable to differential equations for continuous systems.

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

Results are presented in Mats Andersson's PhD thesis. The current research includes modeling and simulation of chattering and sliding mode behavior.

Modeling and Simulation of Power Plants

Researchers: Bernt Nilsson, Jonas Eborn, Rodney Bell, and Karl Johan Åström

This work is a cooperation with Sydkraft Konsult AB and the aim is to develop libraries of basic unit models for thermal power generation plants.

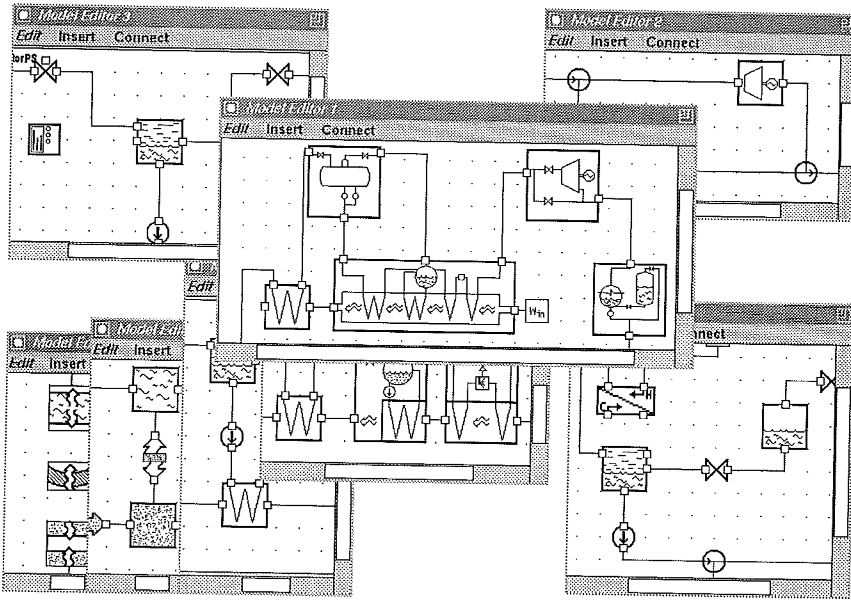


Figure 4.5 Omola models for a heat recovery steam generation system.

The models are developed in Omola and are separated into three levels: systems, units and subunits. Systems are application oriented models described as a structure of units. Examples of systems are the pan section, the condenser section etc. Unit models are commonly used system components like pumps, valves, heat exchangers etc. Subunit models describe particular phenomena like a volume of medium with dynamic mass and energy or flow resistors with variable friction loss.

One application study focuses particularly on a combined cycle power plant. The plant is composed of a gas turbine and a heat recovery steam generation cycle. Combustion of fuel gas is done in a conventional gas turbine for production of electric power. The exhaust gas enters heat exchangers and boilers for steam generation. The produced steam is expanded in a steam turbine to produce electric power and condensed hot water is used for district heat generation.

A significant effort has been devoted to develop new improved models for the steam generation process. This work has been done in collaboration with Dr Rodney Bell of Macquire University in Australia. The key idea is to develop simple nonlinear models based on physics that capture the key phenomena. A major advance this academic year has been in the model for the drum level. The new model captures the shrink-and-swell phenomenon much better than previous models. The model has been validated against data from Sydkraft.

Applications

The major applications projects are in robotics, which also includes real time control, fuzzy control, and control of rolling mills. During the academic year there were also a number of smaller projects.

Robotics

Researchers: Rolf Johansson, Klas Nilsson, and Anders Robertsson

The laboratory for robotics 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 analysis.

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.

Another main 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 and further research 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 established during the year. A major effort in this project is to integrate aspects of control, sensor fusion and application demands.

Real-Time Control

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

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

1. Improvements of traditional (industrially accepted) approaches.
2. Use of formal methods to ensure correctness.
3. Application aspects for embedded control systems that are open and layered.

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

For the traditional approach, a real-time kernel developed within the department has been improved and extended. It allows us to easily introduce new real-time solutions. The kernel currently supports M68k processors, Windows NT and Sun Solaris. Programming languages currently used are C++, Modula-2, and C.

The study of formal methods was started more recently. It has so far mainly focused on the so called synchronous approach. We try to put industrial engineering aspects on theoretical results.

Industrial robot control systems are used as a typical demanding real-time application. We have a well proven experimental platform including two ABB robots controlled from our VME-based computers with Sun workstations being used as host computers. This means that the real-time research is well integrated with the robotics research.

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

High-Level Grafcet for Supervisory Sequential Control

Researchers: Charlotta Johnsson, Karl-Erik Årzén

This project is funded by NUTEK under the REGINA programme. Sequential control is extremely important in industry both for continuous, discrete and batch processes. It is needed both at the direct control level and for supervisory control applications such as, e.g., batch control management. During recent years Grafcet, or SFC, has emerged as an industrial standard for direct level sequential control. Grafcet has its origin in Petri Nets. In parallel to the development of Grafcet, High-Level Petri nets have been developed from ordinary Petri Nets. High-Level Petri nets combine the expression power of high-level programming languages with the formal specification language properties of Petri Nets while preserving the user-friendly graphical representation.

The goal of the project is to develop Grafcet into High-Level Grafcet and thereby make Grafcet amenable also to supervisory level applications. The work is based on Grafchart, a Grafcet toolbox that has been

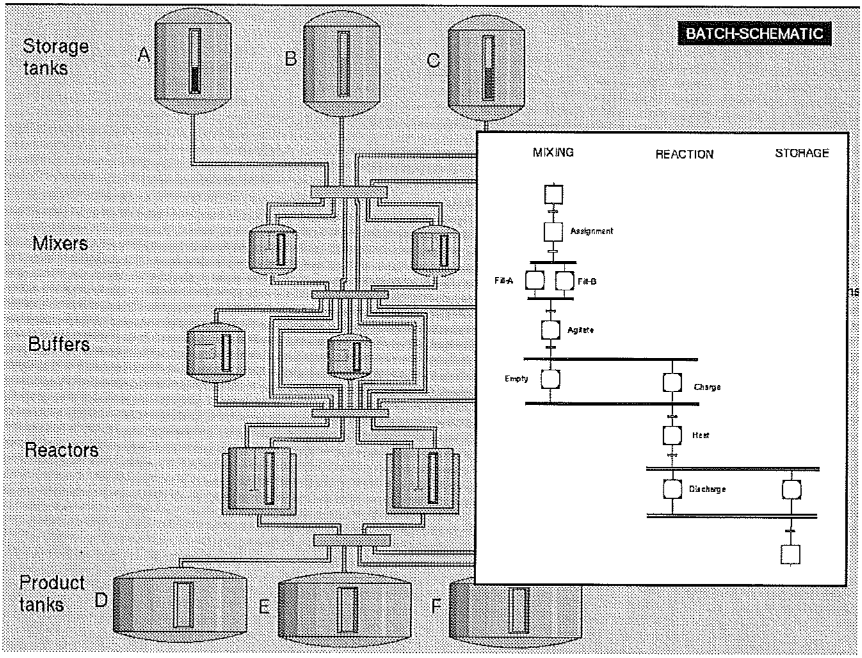


Figure 4.6 Batch process with recipy.

applied in industry with great success. The project also studies exception handling in Grafcet and how High-Level Grafcet can be used for event and alarm handling.

The major application area in the project is multi-purpose batch processes. In this context it is investigated how High-Level Grafcet can be used for recipe representation according to SP88, the new ISA standard for batch control. An on-line simulation of a batch cell that has been developed in G2 is used as a test case, see Figure 4.6. The project has an industrial steering and reference committee consisting of members from Alfa-Laval Automation, ABB Industrial Systems, Astra, Kabi-Pharmacia, van den Bergh Foods, and Perstorp.

Rolling Mill Control

Researchers: Lars Malcolm Pedersen and Björn Wittenmark

The goal of this project is the improvement of the thickness tolerances of the plates rolled by the plate mill at The Danish Steel Works Ltd. (DDS) in Frederiksværk, Denmark. The project is supported by DDS and The Nordic Fund for Technology and Industrial Development. The idea in the project is that the improvement of the thickness accuracy can be obtained by designing a better controller for the process. The project includes literature study, development of dynamical models, and design of suitable controllers for the process.

The project has resulted models for different subprocesses of the rolling process. The models are obtained through a combination of physical model-building and system identifications. The models are based on data collected at the plant. The data are quite unique and have given good insights in how to model the total process. Multivariable controllers based on feedback linearization and eigenspace design have been derived and tested in simulations.

Timing problems in real-time systems

Researchers: Johan Nilsson, Björn Wittenmark and Bo Bernhardsson

This is a subproject within the DICOSMOS project, (Distributed Control of Safety Critical Mechanical Systems). DICOSMOS is a cooperation between Department of Computer Engineering, CTH, Department of Mechanical Elements, KTH, and Department of Automatic Control, LTH. Our part of the project is to develop methods for minimizing effects of communication delays in distributed control systems.

Many real-time systems are implemented as multiprocessor or distributed computer systems and the different tasks are performed in different processors. Processors may be connected to different sensors and actuators and configured to cooperate in performing one or more feedback control functions. As a consequence timing problems can arise when implementing real-time control systems. For example, the network can cause time-varying delays in the communication between different parts of the system, and the multiplexing of several tasks by operating systems can cause unacceptable time-variations for control purposes.

By modeling the communication delay as independent stochastic processes it is possible to evaluate different control schemes. By making a separation hypothesis to separate state estimation and control design it has been possible to derive new control algorithms with superior performance compared to other methods suggested in the literature.

Fuzzy Control

Researchers: Karl-Erik Årzén, and Mikael Johansson

The impact of fuzzy logic on design of controllers has increased dramatically since the first industrial application, the control of a cement kiln, by Holmblad and Ostergard in the beginning of the eighties. Fuzzy logic was introduced already in 1965 by Zadeh, but the applications to control were popularized by the so called inference-rules of fuzzy logic in 1973. These rules make it possible to describe the control action in terms of `if ... then ... else`-constructions that mimics the human way of doing manual control.

The research at the department covers both the theory and practice of fuzzy control. One of the more important areas is analysis of fuzzy controllers which is motivated by the need to understand how fuzzy controllers work. The current work is focused on viewing fuzzy control as a nonlinear interpolation method.

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

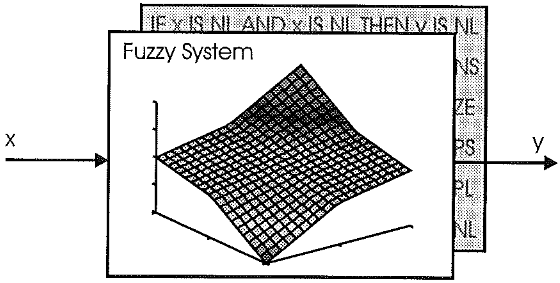


Figure 4.7 Two views of fuzzy control.

FALCON: The department is an associated member of the Esprit-III Basic Research Working Group FALCON (Fuzzy Algorithms for Control). The aim of the working group is to "meet the Japanese and American challenge in the area of Fuzzy Control by pooling efficiently existing European potentials in the areas of Artificial Intelligence, Control Engineering and Operations Research." The coordinator for the project is ELITE – European Laboratory for Intelligent Techniques Engineering in Aachen and the partners consist of eight European universities and one industry. During 94/95 two project meetings were held in Aachen and at Mallorca.

Biomedical Modeling and Control

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

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

The work is supported by the Swedish Medical Research Council (MFR) and the Faculty of Medicine, Lund University.

Collaboration

The department is participating in two networks in the EU Human Capital and Mobility Program. The network *Nonlinear and Adaptive Control* is a cooperation between seven different universities and the network *European Robust and Adaptive Control Network—EURACO Network* consists of 12 universities. There has been a large exchange of visitors within the networks, Lund has been one of the most popular cites to visit.

We are also a member of the ESPRIT project "Tools for the Analysis of Hybrid Systems." This participation has given very good inspiration and has led to a NUTEK project on Heterogeneous control in collaboration with a small company in Malmö.

Funding

Lund University provides partial support for graduate students. The majority of our research is, however, externally funded from governmental agencies. For the academic year 1994–95 we have had the following contracts:

- TFR – Block grant
- TFR – Adaptive control
- NUTEK – Modelling and simulation of complex systems

- NUTEK – Moving autonomous systems
- NUTEK – Autonomous control
- NUTEK – Heterogeneous systems
- NUTEK – Real time systems
- NUTEK – Safety critical systems
- NUTEK – Grafcet
- ITM – Fuzzy control
- Sydkraft – Modeling of thermal systems

The Block grant from TFR is long range and some of the NUTEK projects are also long range. Several projects do, however, have a duration of only two years. To match these with the duration of a PhD, which is much longer, we have an internal research planning which 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.

We are also engaged in the following European projects:

- FALCON
- HCM Project Nonlinear and adaptive control
- HCM Project Robust and adaptive control
- ESPRIT Tools for the Analysis of Hybrid System

These projects are all supported by NFR.

5. Research-Staff Activities

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

Mats Åkesson

MSc, graduate student since September 1994. Currently working on integrated control and diagnosis. Also interested in applications in biotechnology and in educational issues.

Lennart Andersson

MSc, graduate student since 1993. He is interested in modeling and identification of dynamical systems. Current research is modeling of uncertain systems.

Mats Andersson

Research associate, PhD since January 1995. He joined the department in 1986. Major research interests are modeling and simulation of dynamical systems, object-oriented technologies, hybrid and real-time systems, and computer aided control engineering. He has been involved in the European ESPRIT project "Tools for the Analysis of Hybrid Systems." in which the Department of Automatic Control participates. In August 1995 he left the department for a new position at Volvo Technological Department in Gothenburg.

Karl-Erik Årzén

Research associate, PhD (1987). Joined the department in 1981. His research interests are Petri Nets and Grafcet, monitoring and diagnosis, fuzzy control, real-time systems and real-time applications of Artificial Intelligence. During 1994/95 he organized the IFAC Workshop on Computer Software Structures Integrating AI/KBS Systems in Process Control, which was held at the department.

Årzen is the project leader for the NUTEK project "High-Level Grafcet for for supervisory sequential control," for the ITM project "Fuzzy Control" and for the TFR project "Integrated Control and Diagnosis."

Karl Johan Åström

Professor and head of the department since 1965. His research interests are stochastic control, system identification, adaptive control, computer control, and computer-aided control engineering. He participates in many research projects at the department.

During December 1994 through March 1995 he was Visiting Professor at Tokyo Institute of Technology, Japan. He held the Nippon Steel Chair of Intelligent Control. During his stay in Japan he worked on adaptive backlash compensation and control of inverted pendulum.

Bo Bernhardsson

Research associate, PhD. Joined the department in 1987 and took his PhD in 1992. After that he spent 8 months as a post-doc at IMA, University of Minnesota. Interested in system theory, robust control and control applications. During 1994/95 he has been working with the projects "Control of Uncertain Systems" and "Timing Problems in Real-Time Systems."

Jonas Eborn

MSc, graduate student since January 1995. Interested in computer aided control engineering, physical system modelling and numerical analysis. He is working in the NUTEK project "Complex Technical Systems." During 1994 he participated in a project about modelling of thermal power plants in cooperation with the power company Sydkraft AB.

Johan Eker

MSc, graduate student since January 1995. Main interests are implementation of control systems and real-time languages. He is involved in the project "Application Specific Real-Time Systems."

Erik Gustafson

MSc, graduate student since September 1994. Currently working on modeling of power systems. Also interested in non-linear control and in educational issues.

Per Hagander

Associate professor, PhD (1973). Has been with the department since 1968. Works with linear system theory and with applications in biotechnology and medicine.

During 94/95 he worked with Anders Hansson on the Minimum Upcrossing controller and singular LQG-problems. He also had preliminary contracts with Pharmacia BioScience Center on multivariable control of genetically engineered *E. coli* together with the Department of Biotechnology.

Tore Hägglund

Associate Professor, PhD (1984). Has been at the department since 1978 except for four years when he worked at SattControl Instruments AB. He is responsible for the economy at the department. His main research interests include process control, PID control, adaptive control, and fault detection.

Hägglund participates in the NUTEK project "Autonomous Control." In this area, a new research project concerning friction compensation in control valves has been initiated, and promising field tests have been performed.

Anders Hansson

PhD since May 1995. He joined the department in 1989 and became Lic Tech 1991. His research interests concerns both theory and applications. The major research areas has been in the fields of stochastic control theory, linear systems, fuzzy logic, control applications, image interpolation, and telecommunications. Anders Hansson left the department in June 1995. In October he will start as a post-doc at University of Stanford, California.

Karl Henrik Johansson

MSc, graduate student since 1992. Among his research interests are relay feedback systems and structuring of multivariable control systems. He has been cooperating with the control group at ABB Industrial Systems AB in a project concerning multivariable control for industrial processes.

During two months in the summer of 1994, Karl Henrik Johansson visited International Institute of Applied System Analysis in Laxenburg, Austria, as a Peccei scholar. There he worked with analysis of macroeconomic models.

Mikael Johansson

MSc, graduate student since 1994. His research interests include nonlinear control, modeling and identification. He is currently working in the ITM project “Design and Tuning of Fuzzy Controllers Based on Nonlinear Control Theory”.

During May–July 1995 he visited the Hong Kong University of Science and Technology, where he was working with Professor Li-Xin Wang.

Rolf Johansson

Associate professor, PhD (1983), MD (1986). Active at the department since 1979. He is the Director of Studies at the department. His research interest are in system identification, robotics and nonlinear systems, neurophysiology. He is the coordinating director of “Lund Research Programme in Autonomous Robotics,” which is a project sponsored by NUTEK.

Charlotta Johnsson

MSc, Graduate student since 1993. She is interested in supervisory control with focus on batch recipe management. She is currently working in the NUTEK project "High-Level Grafcet for Supervisory Sequential Control."

During 1995 she visited the school of Chemical Engineering at Purdue University USA for 2,5 months. This stay was a part of the research exchange between the Dept. of Automatic Control in Lund and Prof. Venkatasubramanian's group at Purdue University. During the stay she worked in the project "Automating Operating Procedure Synthesis for Batch Chemical Plants".

Ulf Jönsson

MSc, graduate student since 1990. His research interests include robustness analysis of feedback systems and in particular stability analysis of systems with time-varying parameters and various nonlinearities from applications. Ulf visited Massachusetts Institute of Technology in December 1994. During the spring 1995 he visited Technical University of Denmark, California Institute of Technology, Stanford University and U.C. Berkeley. He was also responsible for the organization of the Lund-Lyngby day on Control on May 30, 1995.

Per-Olof Källén

Finished his PhD in November 1994. His research interests have been directed into adaptive control based on frequency domain viewpoints. From March 1995 he is employed at Volvo Truck Company in Gothenburg, where he is working on computer based control of heavy diesel engines.

Jörgen Malmborg

MSc, DEA, graduate student since 1991. His research interests are nonlinear control, especially the area of switched and hybrid control systems. He is working within the project on hybrid systems and from spring 1995 he is involved in the REGINA project "Heterogeneous Control of HVAC Systems."

Sven Erik Mattsson

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

Mattsson participates in the NUTEK project "Modelling and Simulation of Complex Systems" which is a part of NUTEK's research program "Complex Systems."

Bernt Nilsson

Research Associate, PhD (1993). He has been at the department since 1985. His research interests are process modelling, simulation and control, and he is also interested in batch processing and control. During 1994 Nilsson worked on the K2 model database for modelling of thermal power plants.

Johan Nilsson

MSc, graduate student since 1992. His research interests concerns both theory and applications. The major research areas are in the fields of timing in real-time systems, identification for control, and control applications. He is currently working within the NUTEK project "DICOSMOS."

Klas Nilsson

Lic Tech, graduate student. Came to the department from ABB Robotics in 1988. The main research interests are robot control and real-time systems, but he also likes to work with systems and tools for experimental verification. He is involved in the NUTEK projects "Lund Research Programme in Autonomous Robotics" and "Application Specific Real-Time Systems".

Henrik Olsson

MSc, graduate student since 1990. His main research interest is control of nonlinear systems and his work include modelling and analysis of systems with friction as well as friction compensation in servo systems. He has been working in the TFR-project "Robust and Nonlinear Adaptive Control."

Lars Malcolm Pedersen

MSc, graduate student since 1992. He is an employee of the Danish Steel Works Ltd and works both at DDS and with us. Main research interests are process modeling, system identification, and applying advanced theory to real world processes. He is currently working on the project "Improvement of Rolling Mill Control System."

Anders Rantzer

Research associate, PhD. Came to the department in 1993 after a PhD at KTH and a postdoctoral position at IMA, University of Minnesota. Research interests are in modeling, analysis and design of control systems with uncertainty or nonlinearities. In February 1995, he was awarded the title "docent". During 1994/95 he has mainly been working with the project "Control of Uncertain Systems." In September 1994, he visited the Fields Institute in Canada, to teach a course on the same subject.

Anders Robertsson

MSc, graduate student since 1993. His research interests are in nonlinear control and robotics and he is working in the NUTEK project "Lund Research Programme in Autonomous Robotics."

Anders Wallén

MSc, graduate student since 1991. His main research interests are automatic tuning, signal processing, control loop supervision. He is working in the NUTEK project "Autonomous Controllers."

During 1995, he visited the School of Chemical Engineering, Purdue University, USA, for 2.5 months as part of a research exchange between the Department of Automatic Control, Lund, and Professor Venkatasubramanian's group at Purdue. During the stay he was working in a project on on-line diagnosis of chemical plants using neural networks.

Björn Wittenmark

Professor in Automatic Control since 1989. He joined the department in 1966 and took his PhD 1973. His main research interests are adaptive control, sampled-data systems, and process control. He is working within the projects "Frequency Domain Adaptive Control," "Rolling Mill Control," and "Timing Problems in Real-Time Systems."

6. Our Former Students

The quality of the students we educate is an important indicator of quality of research and teaching. The students are probably also the best vehicle for transferring the knowledge we generate in our research programs and the knowledge we bring in from outside. Since we are dealing with more than 700 students per year, it is not possible for us to keep track of all the students. We do follow, however, our Masters, Lic Tech, and PhD students quite well. The interaction with former students is bidirectional, we have often received very useful feedback from former students who are active in industry.

Master's Students

There are about 30 students that do a masters project in our department each year. The masters thesis can either be done at the department or in industry. Some criticism of industrial MS theses has been raised in international evaluations of the educational programs. A main point has been that the university looses control of an important part of the education of the students. Many of the cases of bad experiences are due to a lack of understanding of what constitutes a good thesis problem. In our view MS theses in industry can be both valuable and well executed.

The thesis projects have been particularly successful in those cases where we have a long-term relation with an industrial group. It is then possible to build up a good understanding of problems that are suitable as thesis project. Such relations are by themselves very useful mechanisms for technology transfer. It is important, however, to institute some mechanism for quality control. Currently it is the supervising faculty that has final responsibility for the quality of the theses, and all theses are presented at seminars at the department. We are discussing additional ways of quality control. One measure that is discussed is to have as a goal that a certain number of MS theses should result

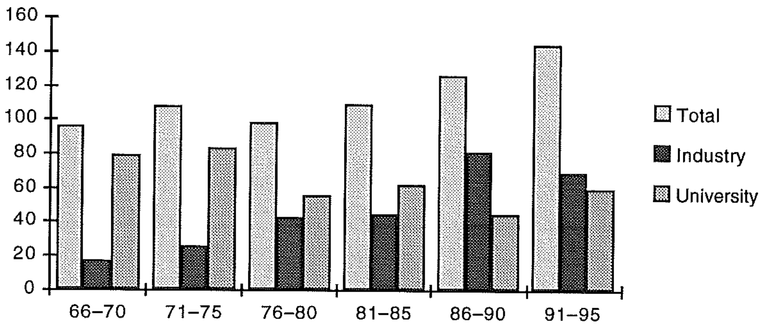


Figure 6.1 Number of Master's students during the period 1965–1995.

in conference papers at conferences with critical reviewing. There are also more general discussions going on at the School of Engineering on quality control of MS theses.

Some statistics about our master's students are given in Figure 6.1. There is a large variability in the numbers. The industrial theses are strongly dependent on the economic conditions. There are many proposals from industry when the economy is bullish and less during recessions. From 1966 to 1985 we had about 20 MSc dissertations per year. This number has now increased to about 30 per year reflecting a similar increase in the total number of students. There is also a trend that the MSc theses in industry has increased over the years. Today about 50% of the MSc theses are done in industry.

Internationalization A very noticeable change over the past five years is the internationalization. From 1993 six (10%) of our MS-students made their masters theses abroad. In the same period seven foreign student (11%) completed their theses in our department.

Lic Tech Students

This degree has changed significantly over the period. The degree was offered until 1973, when it was abolished. It was then reintroduced in a modified form in 1985. From 1969 to 1973 we graduated 10 Lic Tech, and during the new system 14 students have received the Lic

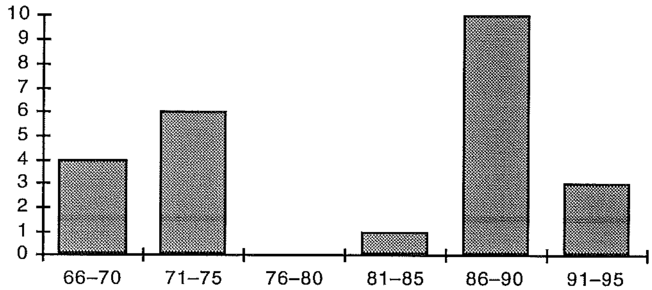


Figure 6.2 Lic Tech degrees awarded in the period 1965–1995.

Tech exam. The average time to complete the exam was 3.5 years, slightly less during 1965–1975 and substantially longer (5.1 years) during 1990–1995. The distribution of the grades over time is shown in Figure 6.2.

The course requirements of the old degree included courses also from a different department. When the degree was reintroduced we had the policy that all PhD students should make a Lic Tech as a natural step towards a PhD. At the same time there was an increase in the average study time, in particular for those students who changed research direction after the Lic Tech. We have now adopted a more flexible policy where students do not necessarily have to take the intermediate degree. We also strongly discourage the students to change research directions. In the new system we require that the students do one and a half year of course-work and a thesis corresponding to at least one year of full-time studies. The majority of the students continue for a PhD after their licentiate. Five students left for industry after the Lic Tech degree.

A list of all graduated students is given at the end of this section.

PhD Students

The number of PhD students have varied over time. After the start of the department there was a gradual build up of students to a maximum of 18 in 1971. During the early 1980 this decreased to a minimum of 6 in 1979. The reason for this was increasing cost for keeping PhD

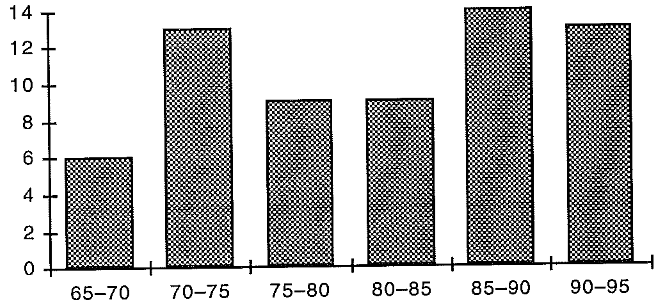


Figure 6.3 PhD and licentiate students at the department in the period 1965–1995.

students and reduction in research funding. The majority of the PhD students were funded externally. Around 1985 the numbers were back to 11, and since then they have varied between 10 and 15. Currently we have 16 PhD students at the department. The average number of graduate students is shown in figure 6.3 for five-year periods.

At the end of the academic year 1994/95 we have graduated 44 PhD students. There are strong variations in the number of graduates that finish every year, the numbers range from 0 to 5 per year. Figure 6.4, that gives averages for five years, shows that in the period of 1971 to 1980 there were on the average two graduates per year. This number dropped during the 1980s to a low of one graduate per year in the end

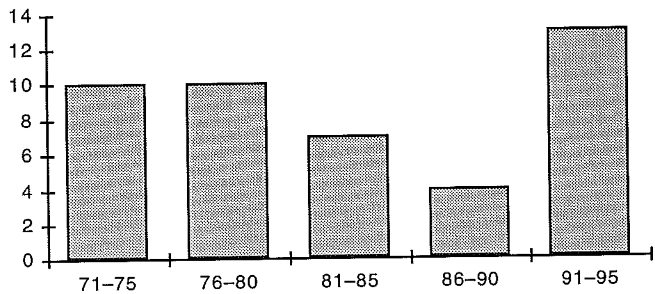


Figure 6.4 PhD degrees awarded in the period 1971–1995.

of the eighties. In the latest five-year period the number of graduates has been increased substantially.

The normal procedure during the past 15 years has been that the PhD students have had full-time positions during their studies. The nominal time for a PhD corresponds to 4 years of study. With 33% teaching this means that the time to complete a PhD will be 6 years. The average time for completion has been longer, about 6.5 years, and the average age at completion is 31.5 years. There is a strong variability in the time to finish a PhD, the shortest time has been 3.7 years and the longest has been 11.9 years. Recently we have been trying to shorten the time by reducing the teaching load. The possibility of doing this depends naturally on the financial situation. It is also difficult to perform such a change in a fair way. It is our ambition to reduce the time for a PhD while maintaining the quality. Time will tell how successful we will be in this effort.

The majority of our graduates enter our program directly after an MSc degree (civ ing). Two of them have spent time in industry before joining us, four have started their graduate studies in another department. The age at the time of completion has varied from 27.5 to 43.8. Among 44 students who have finished their PhD in the department 23 work in academia, 20 works in industry and 1 works for the government. Among 23 graduates working at universities, 8 are professors, and 5

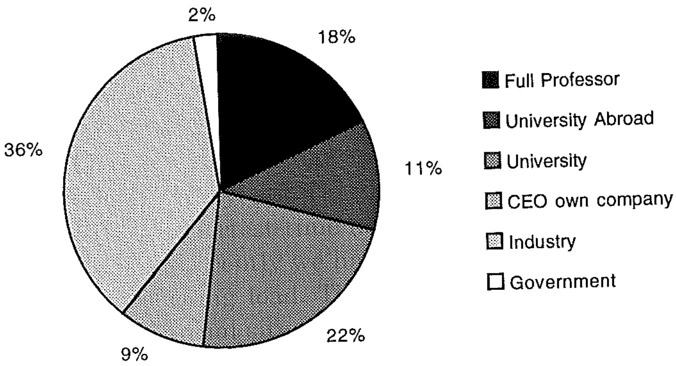


Figure 6.5 Positions of former PhD students.

are working abroad. It is a common pattern that the graduates who aim for an academic position spend several years as post docs in universities abroad. The graduates working in industry are spread over a wide range of industries as can be seen from the list below, four of them have their own companies.

List of students graduated from the department

Name	**Year of exam**		**Position**
Karl Eklund	Lic 1969	PhD 1972	Mykator
Krister Mårtensson	Lic 1970	PhD 1972	Control Development
Björn Wittenmark	Lic 1971	PhD 1973	Prof, LTH
Torsten Söderström	–	PhD 1973	Prof, Uppsala Universitet
Per Hagander	Lic 1971	PhD 1973	LTH
Bengt Pettersson	Lic 1970	–	VD, MoDo AB
Gunnar Bengtsson	–	PhD 1974	First Control Systems AB
Ivar Gustafsson	Lic 1971	PhD 1974	CAP Programmator
Lennart Ljung	–	PhD 1974	Prof, LiTH
Bo Leden	Lic 1971	PhD 1975	MEFOS, Luleå
Ulf Borisson	–	PhD 1975	Ericsson, Tumba
Torkel Glad	–	PhD 1976	Prof, LiTH
Jan Sternby	–	PhD 1977	Gambro
Jan Holst	–	PhD 1977	LTH
Lars Jensen	–	PhD 1978	Prof, LTH
Hilding Elmqvist	–	PhD 1978	Dynasim AB
Lars Pernebo	–	PhD 1978	Alfa Laval Automation
Bo Egardt	–	PhD 1979	Prof, CTH
Cleas Källström	–	PhD 1979	Maritime Consulting SSPA
Johan Wieslander	Lic 1971	PhD 1979	Stora Feldmühle Hylte AB
Sture Lindahl	Lic 1972	–	ABB Relays
Börje Häggman	Lic 1973	–	CELPAP
Per Molander	–	PhD 1979	The Ministry of Finance
Carl Fredrik Mannerfelt	–	PhD 1981	Volvo Lastvagnar AB
Per Olof Gutman	–	PhD 1982	Technion, Haifa
Matz Lenells	–	PhD 1982	Högskolan i Växjö
Rolf Johansson	–	PhD 1983	LTH
Tore Hägglund	–	PhD 1984	LTH
Sven Erik Mattsson	–	PhD 1985	LTH

Lars Nielsen	–	PhD 1985	Prof, LiTH
Bengt Mårtensson	Lic 1985	PhD 1986	Universität Bremen
Karl Erik Årzén	–	PhD 1987	LTH
Jan Peter Axelsson	–	PhD 1989	Kabi Pharmacia
Mats Lilja	–	PhD 1989	LTH, Helsingborg
Bo Eliasson	–	PhD 1990	Sydkraft AB
Lars Rundqwist	Lic 1986	PhD 1991	Saab Scania AB
Ulf Holmberg	Lic 1987	PhD 1991	EPFL, Lausanne
Michael Lundh	–	PhD 1992	ABB, Västerås
Kjell Gustafsson	Lic 1988	PhD 1992	Ericsson
Per Persson	Lic 1987	PhD 1992	Volvo, Göteborg
Anders Wallenborg	Lic 1987	–	Tour & Anderson Innov. AB
Magnus Akke	Lic 1989	–	Sydkraft AB
Ola Dahl	Lic 1989	PhD 1992	Kockums AB, Malmö
Bo Bernhardsson	–	PhD 1992	LTH
Jan Eric Larsson	Lic 1987	PhD 1993	Stanford University, CA
Bernt Nilsson	Lic 1989	PhD 1993	LTH
Per Olof Källén	Lic 1993	PhD 1994	Volvo Lastvagnar
Mats Andersson	Lic 1990	PhD 1995	Volvo Teknisk Utveckling
Anders Hansson	Lic 1991	PhD 1995	Stanford University
Klas Nilsson	Lic 1994	–	LTH

A look on this list shows that our students have indeed done very well.

7. Dissertations

Three PhD dissertations were defended during the year. The abstracts are presented below.

A Frequency Domain Approach to Adaptive Control

Per-Olof Källén
PhD dissertation, 25 November 1994

Opponent: Prof Bo Wahlberg, KTH. Committee: Prof Bo Egardt, CTH; Dr Jan Sternby, Gambro; Prof Pertti Mäkilä, LuTH; Ass Prof Jan Holst, LTH.

Traditionally the certainty equivalence principle is used in most adaptive schemes. The adaptive controllers then often become sensitive to the assumed structure of the estimated models. Too simple models give poor robustness properties. To reduce the problems with undermodeling without introducing large requirements on excitation, an adaptive control scheme, that is based purely on a frequency domain system description, is presented and analyzed in this thesis. The controller design is in this scheme formulated as an approximation problem in the frequency domain. The process information needed in the design is obtained from a bank of estimators, each estimating the frequency response of the process at a given frequency. The scheme gives decoupling of the process estimation in the frequency domain and allows design of low order controllers for high order processes.

The analysis has given valuable insights into the properties of both the estimator, and the controller design, and also resulted in a startup procedure that makes the adaptive controller easier to use. By automating the startup procedure little prior information is needed to use the adaptive controller. A modified design method that gives improved robustness is introduced. Also an on-line scheme for automatic choice of appropriate closed loop bandwidth is presented. With this an adaptive system can be obtained, with closed loop performance, that adapts to changing process characteristics. To demonstrate the use of the scheme, it is evaluated through a number of simulated examples. The simulations show that the scheme has several good properties.

Object-Oriented Modeling and Simulation of Hybrid Systems

Mats Andersson
PhD dissertation, 20 January 1995

Opponent: Prof Wolfgang Marquardt, Germany. Committee: Prof Walter Schaufelberger, ETH Zurich; Prof Torsten Bohlin, KTH; Dr Per Persson, Chalmers; Ass Prof Sven Mattisson, LTH.

Models are important in engineering design and simulation. Existing modeling languages are often specialized for a particular engineering domain or they are specialized for a particular engineering task like simulation. Since good models are hard to develop, it is important that the representation and the modeling tools facilitate reuse of models and model components.

This thesis defines two model representations: a high-level modeling language called Omola and low-level hybrid model formalism called OHM. It also presents an integrated environment for model development and simulation called OmSim. Omola is provided with powerful concepts for creating abstractions and hierarchical decompositions of models. Object-oriented concepts like classes and inheritance are used to support reuse of models and model components. Model behavior is represented as differential and algebraic equations and discrete events. Component interaction is defined by connections that relate terminal interfaces. The meaning of a connection is defined in terms of equations

and event propagations, and it depends on terminal attributes. Composite models can be defined and displayed using graphical editors.

In order to give a precise meaning to Omola models, a low-level formalism for hybrid models is defined. The formalism, called OHM, represent models as sets of variables, parameters, equations, event conditions, and event actions. It has a well-defined meaning in terms of mathematics and logic and it is intended as a common representation in an integrated environment of tools. An OHM can be analyzed algebraically. Well-known graph theoretical methods can be applied to sort equations and to analyze the degrees of freedom in the model and its index. Superfluous variables and equations can be eliminated to reduce the size of the model. Proper models can be translated into more specific representations suitable for numerical simulation. Methods for this are discussed in the thesis.

OmSim is an implementation of an environment supporting development and simulation of Omola models. The architecture of OmSim is presented and some of the important design issues are discussed.

Stochastic Control of Critical Processes

Anders Hansson
PhD dissertation, 5 May 1995

Opponent: Prof Jan H van Schuppen. Committee: Prof Jakob Stoustrup, DTU; Prof Vladimir Kucera, Prague; Prof Holger Rootzén, CTH; Ass Prof Rolf Johansson, LTH.

Stochastic control of critical processes is treated. The critical process signal should not exceed a certain level that can be either physical or artificial. Examples of the former are such levels that cannot be exceeded without catastrophic consequences, e.g., explosion. One example on the latter is alarm levels, which if they are exceeded will initiate emergency shutdown or a change in operational conditions. Another

example is quality levels, which if they are exceeded will cause unsatisfied customers. Common to the critical processes are that they enter their critical region abruptly as a signal exceeds a limiting level. The main contributions of this thesis is the formulation of critical control problems in terms of the minimum upcrossing (MU) controller.

The upcrossing criterion is the probability that the controlled signal upcrosses the critical level. It is shown that this stochastic optimization problem can be solved in terms of a one-parametric optimization over linear quadratic gaussian (LQG) control problems. Both continuous and discrete time are treated. Another contribution of the thesis is simple necessary and sufficient conditions for existence of solutions to discrete-time LQG problems. These are used to derive necessary and sufficient conditions for existence of the MU controller. Also discussed in the thesis are the following criteria: the risk criterion, which is the probability that the largest value of the controlled signal exceeds the critical level, and the mean time between failures criterion, which is the mean time between two consecutive upcrossings of the critical level. It is shown that both these criteria can be approximated by the upcrossing criterion. Furthermore, some nonlinear stochastic control problems for critical processes are investigated. Results are obtained for some special problems, but they seem to be hard to generalize.

8. Honors and Awards

Mats Andersson received in May 1995 the *Sydkraft Research Scholarship* for his work in object-oriented modeling and simulation.

Karl-Erik Årzén received the first price in the Gensym University G2 Application Contest for the paper "Using multi-view objects for structuring plant databases."

Karl Johan Åström was elected as foreign associate of the USA National Academy of Engineering. The academy has 1790 US members and 151 foreign associates. Election to the academy is among the highest professional distinctions accorded an engineer.

Ulf Jönsson received the *Saab-Scania Scholarship* in April 1995.

9. Personnel and Visitors

During the year the following persons have been employed at the department. The list shows the *status of June 1995* if nothing else is mentioned.

Personnel

Professors

Karl Johan Åström
Björn Wittenmark

Associate Professors

Per Hagander
Tore Hägglund
Rolf Johansson

Research Associates

Karl-Erik Årzén
Bo Bernhardsson
Sven Erik Mattsson
Bernt Nilsson
Anders Rantzer

Research Engineers

Leif Andersson
Anders Blomdell
Rolf Braun
Tomas Schönthal

PhD Students

Lennart Andersson
Mats Andersson (graduated January 1995)
Jonas Eborn (from January 1995)
Johan Eker (from January 1995)
Erik Gustafson
Anders Hansson (graduated May 1995)
Karl Henrik Johansson
Mikael Johansson
Charlotta Johnsson
Ulf Jönsson
Per-Olof Källén (graduated November 1994)
(left the department January 1995)
Jörgen Malmborg
Johan Nilsson
Klas Nilsson
Henrik Olsson
Anders Robertsson
Anders Wallén
Mats Åkesson

Secretaries

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

Temporary Appointments

Morten Hemmingsson (4 months)

Email addresses

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
```

Visiting Scientists

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

Mr Lars Malcolm Pedersen
The Danish Steelworks Ltd, Frederiksværk, Denmark
(From 1 July 1992)

Mr Raul Savimaa
Tallinn Technical University, Estonia
(1 Feb – 30 July 1994)

Mr Michele Gianino
Politecnico di Torino, Italy
(17 March – 3 Oct 1994)

Mr Peter Müller
Technische Universität München, Germany
(10 May – 24 Nov 1994)

Mr Jesus Pico
Valencia, Spain
(20 June – 15 Aug 1994)

Mr Emanuele Carpanzano
Mr Fabio Formenti
Milano
(1 Aug – 31 Oct 1994)

Prof Alexander Megretski
Iowa State University
(1–18 Aug 1994)

Mr Eric Denolin (ERASMUS)
Free University of Brussels, Belgium
(23 Aug 1994 – 27 Feb 1995)

Mr Andrej Barabanov
S:t Petersburg State University, Russia
(28 Aug – 19 Sep 1994)

Prof Munther Dahleh
Massachusetts Institute of Technology
(29 Aug – 2 Sep 1994)

Mr Sanjay Lall
Cambridge University
(1 Sep – 31 Oct 1994)

Mr Jan Peter Meeuwse (ERASMUS)
Eindhoven University of Technology, The Netherlands
(1 Sep 1994 – 20 July 1995)

Mr Raghunathan Rengaswamy
Mr Dinkar Mylaraswamy
Purdue University
(3 Oct – 16 Dec 1994)

Mr Luis Antonio Rosa Sobral (ERASMUS)
University of Coimbra, Portugal
(19 Oct 1994 – 10 July 1995)

Prof Jan Willems
University of Groningen, The Netherlands
(19–24 March 1995)

Mr Martin Weiss
Univ of Groningen, The Netherlands
(17–24 March 1995)

Prof Rod Bell
Macquarie University, New South Wales, Australia
(1 April – 30 June 1995)

Prof David Mayne University of California, USA
(21–27 May 1995)

Mr Costas Konstantinos Yalirakis (ERASMUS)
Mr Alexander Kennedy Urquhart (ERASMUS)
Ms Maria-Christina Laiou (ERASMUS)
Imperial College of Science, Technology and Medicine, London, UK
(1 May – 31 Aug 1995)

Ms Lourdes Penalver
Universidad Politecnica de Valencia, Spain
(1 June – 31 July 1995)

10. Publications

Books and Proceedings

Årzén, Karl-Erik, Ed.: *Computer Software Structures Integrating AI/KBS Systems in Process Control.* Elsevier Science, 1994. IFAC Workshop in Lund, Sweden.

Åström, Karl Johan, G. C. Goodwin, and P. R. Kumar, Eds.: *Adaptive Control, Filtering, and Signal Processing,* volume 74 of *IMA Volumes in Mathematics and its Applications.* Springer-Verlag, 1995.

Åström, Karl Johan, and Tore Hägglund: *PID Controllers: Theory, Design, and Tuning.* Instrument Society of America, Research Triangle Park, NC, second edition, 1995.

Åström, Karl Johan, and Björn Wittenmark: *Adaptive Control.* Addison-Wesley, Reading, Massachusetts, second edition, 1995.

Papers

Årzén, Karl-Erik: "Grafcet for intelligent supervisory control applications." *Automatica,* **30:10**, pp. 1513–1526, 1994.

Årzén, Karl-Erik, Anders Wallén, and T. F. Petti: "Model-based diagnosis—state transition events and constraint equations." In Tzafestas and Verbruggen, Eds., *Artificial Intelligence in Industrial Decision Making, Control and Automation.* Kluwer Academic Publishers, 1995.

Åström, Karl Johan: "The future of control." *Modeling, Identification and Control,* **15:3**, pp. 127–134, 1994.

Åström, Karl Johan: "Oscillations in systems with relay feedback." In Åström *et al.*, Eds., *Adaptive Control, Filtering, and Signal Processing,* volume 74 of *IMA Volumes in Mathematics and its Applications,* pp. 1–25. Springer-Verlag, 1995.

Åström, Karl Johan, C. C. Hang, and B. C. Lim: "A new smith predictor for controlling a process with an integrator and long dead-time." *IEEE Transactions on Automatic Control*, **39:2**, February 1994.

Bernhardsson, Bo: "Robust performance optimization of open loop type problems using models from standard identification." *Systems and Control Letters*, pp. 79–87, 1995.

Canudas de Wit, C., H. Olsson, K. J. Åström, and P. Lischinsky: "A new model for control of systems with friction." *IEEE Transactions on Automatic Control*, **40:3**, 1995.

James, John, Francois Cellier, Grantham Pang, John Gray, and Sven Erik Mattsson: "The state of computer-aided control system design (CACSD)." *IEEE Control Systems*, **15:2**, pp. 6–7, April 1995.

Johansson, Rolf: "Multivariable system identification via continued-fraction approximation." *IEEE Transactions on Automatic Control*, **40:3**, pp. 507–512, 1995.

Johansson, Rolf, M. Magnusson, and P. A. Fransson: "Galvanic vestibular stimulation for analysis of postural adaptation." In Taguchi *et al.*, Eds., *Vestibular and Neural Front*, Excerpta Medica, pp. 465–468. Elsevier, Amsterdam, The Netherlands, 1994.

Johansson, Rolf, M. Magnusson, and P. A. Fransson: "Galvanic vestibular stimulation for analysis of postural adaptation and stability." *IEEE Transactions on Biomedical Engineering*, **42:3**, pp. 282–292, 1995.

Johansson, Rolf, M. Magnusson, P. A. Fransson, and M. Karlberg: "Discrimination between patients with acoustic neuroma and with peripheral vestibular lesion by human posture dynamics." *Acta Otolaryngologica (Stockh)*, **114**, pp. 479–483, 1994.

Lundh, Michael, and Karl Johan Åström: "Automatic initialization of a robust self-tuning controller." *Automatica*, **30:11**, pp. 1649–1662, November 1994.

Qiu, Li, Bo Bernhardsson, Anders Rantzer, E. J. Davison, P. M. Young, and J. C. Doyle: "A formula for computation of the real stability radius." *Automatica*, **31:6**, pp. 879–890, 1995.

Rantzer, Anders: "Uncertain real parameters with bounded rate of variation." In Åström *et al.*, Eds., *Adaptive Control, Filtering and*

Signal Processing. Springer-Verlag, 1994.

Rantzer, Anders, and A. Megretski: "A convex parameterization of robustly stabilizing controllers." *IEEE Transactions on Automatic Control*, **39:9**, pp. 1802–1808, September 1994.

Sagatun, S. I., and Rolf Johansson: "Optimal and adaptive control of underwater vehicles." *Modeling, Identification and Control*, **15**, pp. 245–252, 1994.

Conference Papers

Andersson, Lennart, and Anders Hansson: "Extreme value control of a double integrator." In *Proc. 33rd IEEE Conference on Decision and Control*, Orlando, Florida, 1994.

Andersson, Mats: "Representation and simulation of combined continuous time and discrete event models in omola." In Langemyr, Ed., *Proceedings of the 36th SIMS Simulation Conference*, Stockholm, Sweden, August 1994. Scandinavian Simulation Society.

Andersson, Mats: "Representation and simulation of hybrid systems in OmSim." In Bouajjani and Maler, Eds., *Second European Workshop on Real-Time and Hybrid Systems*, Grenoble, France, May 1995. VERIMAG Laboratory.

Årzén, Karl-Erik: "Parameterized high-level grafcet for structuring real-time KBS applications." In *Preprints 2nd IFAC Workshop on Computer Software Structures Integrating AI/KBS Systems in Process Control*, pp. 105–110, Lund, Sweden, August 1994.

Årzén, Karl-Erik: "Integrated control and diagnosis of sequential processes." In *IFAC Workshop on On-Line Fault Detection and Supervision on the Chemical Process Industries*, Newcastle, UK, 1995.

Åström, Karl Johan: "Automatisation and control of power plants and facilities." In *A New Age for Electricity. Proceedings IERE Forum*, pp. 241–253, Monte-Carlo, Monaco, 1995.

Åström, Karl Johan, and Johan Nilsson: "Analysis of a scheme for iterated identification and control." In *10th IFAC Symposium on System Identification, SYSID'94*, Copenhagen, Denmark, 1994.

Hansson, Anders, and Per Hagander: "On the existence of minimum upcrossing controllers." In *Proceedings of the IFAC Symposium on Robust Control Design*, pp. 204–209, Rio de Janeiro, Brazil, September 1994.

Johansson, Mikael: "Rule based interpolating control—fuzzy and its alternatives." In *Preprints 2nd IFAC Workshop on Computer Software Structures Integrating AI/KBS Systems in Process Control*, pp. 205–210, Lund, Sweden, August 1994.

Johansson, Rolf: "Multivariable system identification via continued-fraction approximation." In *Proc. 33rd IEEE Conference on Decision and Control*, pp. 2288–2293, Lake Buena Vista, Florida, December 1994.

Johnsson, Charlotta, and Karl-Erik Årzén: "High-level grafcet and batch control." In *Symposium ADPM'94—Automation of Mixed Processes: Dynamical Hybrid Systems*, Brussels, Belgium, 1994.

Jönsson, Ulf, and Anders Rantzer: "Systems with uncertain parameters—Time-variations with bounded derivatives." In *Proceedings of the IEEE Conference on Decision and Control*, 1994.

Jönsson, Ulf, and Anders Rantzer: "A unifying format for multiplier optimization." In *Proceedings of the 1995 American Control Conference*, 1995.

Källén, Per-Olof: "A frequency domain identification scheme." In *10th IFAC Symp on System Identification SYSID'94*, Copenhagen, Denmark, 1994.

Li, Zheng, R. J. Evans, and B. Wittenmark: "Minimum variance prediction for linear time-varying systems." In *10th IFAC Symposium on System Identification*, volume 2, pp. 355–360, Copenhagen, Denmark, 1994.

Nilsson, Bernt: "Modeling and Simulation of a Batch Process in Omola." In *Proc. of the 36th SIMS Simulation Conference*, pp. 35–40, 1994.

Nilsson, Klas: "Software for embedded DSPs." In *Proceedings from The American Control Conference*, 1994. Invited Paper.

Pedersen, Lars Malcolm: "Identification of hydraulic system on rolling mill." In *Preprints ot the 10th IFAC Symposium on System Identification*, volume 3, pp. 337–342, 1994.

Pedersen, Lars Malcolm: "Modeling and identification of hot rolling mill." In *Preprints of the 1995 American Control Conference*, Seattle, Washington, 1995.

Rantzer, Anders, and A. Megretski: "System analysis via Integral Quadratic Constraints." In *Proceedings of Conference of Decision and Control*, 1994.

Sagatun, S. I., and Rolf Johansson: "Optimal and adaptive control of underwater vehicles." In Sciavicco *et al.*, Eds., *Preprints of Fourth IFAC Symposium on Robot Control*, pp. 953–958, Capri, Italy, September 1994.

Wittenmark, Björn: "Mechanical engineering control education." In *Dynamic Systems and Control 1994, Preprints 1994 International Mechanical Engineering Congress and Exposition*, volume 2, pp. 1051–1052, Chicago, Illinois, 1994. Invited paper.

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

Wittenmark, Björn, Johan Nilsson, and M. Törngren: "Timing problems in real-time control systems." In *Proceedings of the 1995 American Control Conference*, Seattle, Washington, 1995.

11. Reports

Dissertations

Andersson, Mats: *Object-Oriented Modeling and Simulation of Hybrid Systems.* PhD thesis ISRN LUTFD2/TFRT--1043--SE, December 1994.

Hansson, Anders: *Stochastic Control of Critical Processes.* PhD thesis ISRN LUTFD2/TFRT--1044--SE, March 1995.

Källén, Per-Olof: *A Frequency Domain Approach to Adaptive Control.* PhD thesis ISRN LUTFD2/TFRT--1042--SE, November 1994.

Master Theses

Ahnelöv, Mats: "Tidsoptimering av en lödprocess," (Time optimization of a solder process). Master thesis ISRN LUTFD2/TFRT--5530--SE, June 1995.

Åkesson, Mats: "Etude comparative des performances et propriétés de la commande L/A," (A comparative study of performance and properties of L/A control). Master thesis ISRN LUTFD2/TFRT--5511--SE, July 1994.

Anell, Per: "Modeling of multibody systems in Omola." Master thesis ISRN LUTFD2/TFRT--5516--SE, September 1994.

Bergstrand, Jesper: "Control of poppet valves." Master thesis ISRN LUTFD2/TFRT--5513--SE, August 1994.

Bistedt, Fredrik: "Neurala nätverk i Sattline," (Neural networks in Sattline). Master thesis ISRN LUTFD2/TFRT--5514--SE, August 1994.

Gianino, Michele: "Adaptive control of systems with dead zones." Master thesis ISRN LUTFD2/TFRT--5519--SE, October 1994.

Gustafson, Erik: "Active damping of subsynchronous resonance." Master thesis ISRN LUTFD2/TFRT--5509--SE, July 1994.

Hemmingsson, Morten: "Digital reglering av ett resonant servo med friktion," (Digital control of a resonant servo with friction). Master thesis ISRN LUTFD2/TFRT--5515--SE, September 1994.

Joelson, Anders: "Simulation of a series hybrid vehicle." Master thesis ISRN LUTFD2/TFRT--5510--SE, August 1994.

Laurin, Olof: "Öppna regulatorer för inbyggda system," (Open controllers for embedded systems). Master thesis ISRN LUTFD2/TFRT--5528--SE, April 1995.

Linder, Jerker: "Validering och objektorienterad modellering av transformator," (Validation and object-oriented modelling of a transformer). Master thesis ISRN LUTFD2/TFRT--5526--SE, March 1995.

Lundgren, Staffan: "Modellering och design av ett HOD-reglersystem," (Modeling and design of an HOD system). Master thesis ISRN LUTFD2/TFRT--5520--SE, November 1994.

Müller, Peter: "Control of systems with backlash." Master thesis ISRN LUTFD2/TFRT--5521--SE, November 1994.

Nyquist, Martin, and Magnus Scherman: "Modellering av processer i reglersystem för effekt, tryck och matarvatten i kokarvattenreaktorer," (Modeling of processes in the control systems for reactor pressure, power, and feedwater in boiling water reactor). Master thesis ISRN LUTFD2/TFRT--5525--SE, January 1995.

Nyström, Marcus: "Prediktion av OMX-index med holografiska neurala nätverk," (Prediction of OMX-index with holographic neural networks). Master thesis ISRN LUTFD2/TFRT--5529--SE, April 1995.

Olshov, Jörgen: "Data classification using neural networks—applications in control and chemometrics." Master thesis ISRN LUTFD2/TFRT--5518--SE, September 1994.

Pettersson, Magnus: "Dynamic process simulation of wet systems for flue gas cleaning." Master thesis ISRN LUTFD2/TFRT--5523--SE, January 1995.

Rosenberg, Michael: "Nonlinear frequency of an ultrasonic generator." Master thesis ISRN LUTFD2/TFRT--5522--SE, January 1995.

Sanfridson, Martin: "Disturbances in paper machine control systems caused by nonlinear components." Master thesis ISRN

LUTFD2/TFRT--5517--SE, September 1994.

Sartor, Johan: "Modeling and analyse of a power system." Master thesis ISRN LUTFD2/TFRT--5524--SE, January 5524.

Sjögren, Jerker: "Fuzzy control of a domestic hot water system." Master thesis ISRN LUTFD2/TFRT--5512--SE, September 1994.

Sobral, Luís António Rosa: "System identification applied to ultrasonic detection problems." Technical Report ISRN LUTFD2/TFRT--5532--SE, June 1995.

Sonnerfeldt, Jonas: "Matlab som 'compute server' för inbyggda system – beräkning av robotrörelser," (Matlab as a compute server for embedded systems—trajectory computation). Master thesis ISRN LUTFD2/TFRT--5527--SE, February 1995.

Other Reports

Bernhardsson, Bo: "Linear quadratic control design—The PhD course 1994." Report ISRN LUTFD2/TFRT--7529--SE, January 1995.

Carpanzano, Emanuele, and Fabio Formenti: "Solution of symbolic linear systems in OmSim using Cramer's rule." Report ISRN LUTFD2/TFRT--7524--SE, October 1994.

Dagnegård, Eva, and Rolf Johansson: "Activity report 1993–1994." Report ISRN LUTFD2/TFRT--4022--SE, December 1994.

Eborn, Jonas, and Bernt Nilsson: "Object-oriented modelling and simulation of a power plant. Application study in the K2 project." Report ISRN LUTFD2/TFRT--7527--SE, December 1994.

Hansson, Anders, and Karl Johan Åström: "Några företag som arbetar med reglerteknik," (Some companies working with automatic control). Report ISRN LUTFD2/TFRT--7525--SE, October 1994.

Johansson, Karl Henrik: "An automatic start-up procedure for multivariable control systems." Report ISRN LUTFD2/TFRT--7526--SE, December 1994.

Johansson, Rolf, Lennart Andersson, and Karl Henrik Johansson, Eds.: "Processidentifiering – projektarbeten våren 1995," (System identification – term papers spring 1995). Report ISRN LUTFD2/TFRT--7532--SE, May 1995.

Jönsson, Ulf: "The IQC by Sundareshan and Thatachar." Report ISRN LUTFD2/TFRT--7533--SE, June 1995.

Jönsson, Ulf, and Anders Rantzer: "A format for multiplier optimization." Report ISRN LUTFD2/TFRT--7530--SE, March 1995.

Jönsson, Ulf, and Anders Rantzer: "On duality in robustness analysis." Report ISRN LUTFD2/TFRT--7534--SE, June 1995.

Megretski, Alexander, and Anders Rantzer: "System analysis via integral quadratic constraints, part 1." Report ISRN LUTFD2/TFRT--7531--SE, April 1995.

Nilsson, Bernt: "Process modeling—a PhD course." Report ISRN LUTFD2/TFRT--7536--SE, June 1995.

Nilsson, Bernt, and Jonas Eborn: "K2 model database—Tutorial and reference manual." Report ISRN LUTFD2/TFRT--7528--SE, December 1994.

Nilsson, Bernt, Jonas Eborn, and Sven Erik Mattsson: "Omola, OmSim och K2 – en kort kurs," (A short course). Report ISRN LUTFD2/TFRT--7535--SE, June 1995.

Nilsson, Johan: "Symbolic evaluation of certain complex integrals." Report ISRN LUTFD2/TFRT--7523--SE, August 1994.

Reports Available

Some abstracts and reports are available by anonymous FTP from

`ftp.control.lth.se` in directory `/pub/techreports`

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,
  S-581 83 Linköping
- UB 2, Svenska Tryckavdelningen, Box 1010, S-221 03 Lund

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

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).

12. Lectures by the Staff

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

Lennart Andersson

Extreme value control of a double integrator. IEEE Conference on Decision and Control, Orlando, Florida. December 15, 1994.

Mats Andersson

Representation and simulation of combined continuous time and discrete event models in Omola. SIMS Simulation Conference, Stockholm. August 18, 1994.

Modelling and simulation of hybrid systems in Omsim. Invited seminar at Linköping University. February 23, 1995.

Representation and simulation of hybrid systems in Omsim. Second European Workshop on Real-Time and Hybrid Systems, Grenoble, France. June 2, 1995.

Karl-Erik Årzén

Parameterized high-level Grafcet for structuring real-time KBS applications. IFAC Workshop on Computer Software Structures Integrating AI/KBS Systems in Process Control, Lund. August 11, 1994.

High-level Grafchart. RWTH Aachen. September 20, 1994.

Modelling for on-line diagnosis. ABB, Västerås. September 27, 1994.

Using multi-view objects for structuring plant databases. Gensym European User Society Meeting, Edinburgh, Invited Lecture. October 20, 1994.

High-level Grafcet and batch control. Symposium ADPM'94—Automation of Mixed Processes: Dynamical Hybrid Systems, Bryssel. November 24, 1994.

Integrated control and diagnosis of sequential Processes. IFAC Workshop on On-line Fault Detection and Supervision in the Chemical Process Industries, Newcastle UK. June 12, 1995.

Karl Johan Åström

Analysis of a scheme for iterated identification and control. IFAC Symposium on SYSID'94 Copenhagen, Denmark. July 5, 1994.

Adventures in adaptation. Maui, Hawaii. Aug 30, 1994.

Advances in autonomous control. Invited Plenary Lecture, IFAC Symposium on Artificial Intelligence in Real Time Control, Valencia, Spain. Oct 5, 1994.

Three lecture series: *Fuzzy logic adaptive controllers.*
Friction compensation.
Object oriented modeling of nonlinear systems. Meeting with the EU Human Capital and Mobility Network on Nonlinear Control Systems – Towards a Design Methodology for Physical Systems, Valencia, Spain. Oct 7, 1994.

Adaptiv reglering av system med enkla olinjäriteter. (Adaptive control of systems with simple nonlinearities. Reglermöte 94, Västerås, Sweden. Oct 25, 1994.

Autonoma regulatorer (Autonomous control). Reglermöte 94, Västerås, Sweden. Oct 2, 1994.

Adaptive control. Department of Automation, University of Science and Technology of China Hefei, Anhui, China. Nov 1, 1994.

Automatic tuning and adaptation. International Workshop on New Directions of Control and Manufacturing, Hong Kong. Nov 7, 1994.

Automatisk inställning av regulatorer. (Automatic Tuning of Controllers). Högskolan i Luleå, Sweden. Nov 15, 1994.

Adaptation and tuning. Invited lecture. Centre for Process Systems Engineering, Imperial College, London, UK. Nov 18, 1994.

Minicourse on Nonlinear Control Theory at the Tokyo Institute of Technology, Tokyo, Japan. *Part 1: Lyapunov stability.* Dec 5, 1994. *Part 2: Input output stability.* Dec 12, 1994. *Part 3: Applications to adaptive control.* Jan 9, 1995 *Part 4: Relay feedback.* Jan 23, 1995. *Part 5: Feedback linearization and backstepping.* Jan 30, 1995.

Adaptation and tuning. 15th SICE Symposium on Adaptive Control, Sakai, Japan. Jan 26, 1995.

Friction models and friction compensation. Center for Process Systems Engineering, Tokyo University, Tokyo, Japan. Feb 7, 1995.

Nonlinear adaptive control. Meeting on Next Generation Control Control Systems, Hakone, Japan. Feb 17, 1995.

Advances in tuning and adaptation. Toshiba Research & Development Center, Ukishima-cho, Kawasaki, Japan. Feb 24, 1995.

Nonlinear adaptive control. Nippon Steel Kimitsu R&D Laboratory, Kimitsu, Japan. March 8, 1995.

Advances in adaptive control. Department of Kyoto, Japan. March 27, 1995.

Towards intelligent control. Commemorative Lecture of the Nippon Steel Chair of Intelligent Control The Embassy of Sweden, Tokyo, Japan. March 30, 1995.

Matching criteria for control and identification. Tokyo Institute of Technology, Oh-okayama, Meguro-ku, Japan. April 6, 1995.

Automation of power plants and facilities. IERE Unipede Conference on A New Age for Electricity, Monaco. April 29, 1995.

Automatic control – ideas and opportunities. ABB Forum for Management of Technology, Västerås, Sweden. May 11, 1995.

Control of systems with friction. Department of Electrical Engineering and Computer Science, University of California, Berkeley, California. June 20, 1995.

The future of control. Symposium on Communication, Control and Computation, Stanford University, Stanford, California. June 20, 1995.

Bo Bernhardsson

Kreiss matrix theorem, Buffon's needle problem and real zeros of random polynomials. Department of Numerical Analysis, Lund, Sweden. May 11, 1995.

Computation of the real stability radius. Invited lecture, Hurwitz Centennial, Ascona, Switzerland. May 23, 1995.

An introduction to H_∞ Control. EURACO Workshop on Robust and Adaptive Control, Dublin. Aug 30, 1994.

Per Hagander

How to solve singular discrete-time Riccati-equations. Invited lecture at LAG, Grenoble. July 11, 1995.

Tore Hägglund

New tuning methods for PID controllers. Reglermöte 94, Västerås, Sweden. October 25, 1994.

Automatic supervision of control valves. Pulp and Paper meeting, Lund. March 8, 1995.

Anders Hansson

Fuzzy anti-reset windup for heater control. 2nd IFAC Workshop on Computer Structures Integrating AI/KBS Systems in Process Controll, Lund, Sweden. August 11, 1994.

On the existence of minimum upcrossing Controllers. IFAC Symposium on Robust Control Design, Rio de Janeiro, Brazil. September 14, 1994.

Karl Henrik Johansson

Convergence rate of agents' learning in macroeconomic models. International Institute of Applied System Analysis in Laxenburg, Austria. August 4, 1994.

An automatic start-up procedure for multivariable control system. Reglermöte 94, Västerås, Sweden. October 26, 1994.

Rolf Johansson

Optimal and adaptive control of underwater vehicles. Fourth IFAC Symposium on Robot Control (SY.RO.CO.'94), Capri, Italy. Sept 21, 1994.

Galvanic vestibular stimulation for analysis of postural stability and adaptation., Int. Symp. Posture and Gait, Matsumoto, Japan. Oct 6, 1994.

Robot control. Dept. Mathematics, Copenhagen University, Denmark. Dec 5, 1994.

Multivariable system identification via continued-fraction approximation. Coordinated Sciences Laboratory, Univ. Illinois at Urbana-Champaign, Illinois, USA. Dec 7, 1994.

Multivariable system identification via continued-fraction approximation. 33rd IEEE Conf. Decision and Control, Lake Buena Vista, Florida, USA. Dec 15, 1994.

Data analysis in posturography. Dept. Physical Therapy, Lund University Hospital, Lund, Sweden; Lecture invited for the 1995. Nordic postgraduate course on *posturography*. May 19, 1995.

Ulf Jönsson

Systems with uncertain parameters—Time-variations with bounded derivatives. Massachusetts Institute of Technology, Florida. Dec 12, 1994.

Systems with uncertain parameters – Time variations with bounded derivatives. 33rd IEEE Conference on Decision and Control, Orlando, Florida. Dec 14, 1994.

LMI computations and duality bounds for robustness analysis. California Institute of Technology. June 8, 1995.

LMI computations and duality bounds for robustness analysis. Stanford University, California. June 14, 1995.

LMI computations and duality bounds for robustness analysis. University of Berkeley, California. June 16, 1995.

A unifying format for robustness analysis. 1995 American Control Conference, Seattle, Washington. June 22, 1995.

Jörgen Malmborg

Fuzzy Heterogeneous Control. FALCON meeting, Aachen, Germany. Sep 19, 1994.

Sven Erik Mattsson

Modelling and simulation of complex systems. NUTEK conference for the research programme "Complex Systems", Stockholm, Sweden. Nov 3, 1994.

Bernt Nilsson

Omola course. An industrial course on Omola and Omsim for Sydkraft Konsult AB, Lund, Sweden. Oct 13–14, 1994.

Modelling and simulation of batch processes with Omola. Reglermöte 94, Västerås, Sweden. Oct 25, 1994.

An object oriented model av a heat exchanger. Reglermöte 94, Västerås, Sweden. Oct 25, 1994.

Object-oriented Modelling and Simulation. Invited lecture, Tetra Pak, Lund, Sweden. Nov 28, 1994.

PhD course *Process Modelling.* 7 lectures and 5 exercises, Department of Chemistry and Chemical Engineering, Lund, Sweden. April 24, 1995.

Johan Nilsson

Stochastic analysis and control of real-time systems with random time delays. California Institute of Technology, Pasadena, California, USA. June 7, 1995.

Stochastic analysis and control of real-time systems with random time delays. Stanford University, Palo Alto, California, USA. June 14, 1995.

Stochastic analysis and control of real-time systems with random time delays. University of California, Berkeley, California, USA. June 16, 1995.

Timing problems in real-time control systems. 1995. American Control Conference, Seattle, Washington, USA. June 22, 1995.

Klas Nilsson

Sensor fusion in industrial robotics. Seminal given at the Department of Computer Science, University of Copenhagen, Denmark. December 5, 1994.

Henrik Olsson

Friction modelling for control design and analysis., Reglermöte 94, Västerås, Sweden. October 26, 1994.

Anders Rantzer

Minicourse of six lectures: *Control of uncertain systems.* Fields Institute, Waterloo, Canada. Sept 24–29, 1994.

On real perturbation values. Invited lecture at INSMATH Conference on Applications of Operator Theory, Winnipeg, Canada. Oct 3, 1994.

System analysis via integral quadratic constraints. University of Toronto, Toronto, Canada. Oct 5, 1994.

System analysis via integral quadratic Constraints. McGill University, Montreal, Canada. Dec 12, 1994.

System analysis via integral quadratic constraints. Conference on Decision and Control, Orlando. Dec 16, 1994.

System analysis via integral quadratic constraints. University of Minnesota, Minneapolis. April 18, 1995.

Spectral analysis of uncertain systems. Iowa State University, Ames, USA. April 21, 1995.

Spectral analysis of uncertain systems. Invited Lecture at SIAM Conference on Control and its Applications, St. Louis, USA. April 27, 1995.

System analysis via integral quadratic constraints., Chalmers University of Technology, Göteborg, Sweden. May 12, 1995.

Invited seminar series of three lectures: *1) On real perturbation values. Invited seminar series: 2) Stability analysis via integral quadratic constraints. Invited seminar series: 3) Performance analysis via integral quadratic constraints.* Universität Bremen, Germany. June 12–16, 1995.

Björn Wittenmark

Minimum variance prediction for linear time-varying systems. 10th IFAC Symposium on System Identification, Copenhagen, Denmark. July 5, 1994.

Backstepping-based techniques., Human Capital and Mobility Workshop on Nonlinear Control Systems, Valencia, Spain. October 6, 1994.

Practical issues and case studies in adaptive control., Invited lecture within IEEE Distinguished Lecture Program, Ithaca, NY. November 2, 1994.

Mechanical engineering control education., Invited lecture, 1994. International Mechanical Engineering Congress and Exposition, Chicago, IL. November 10, 1994.

Invited minicourse on Adaptive Control, five lectures: *Introduction to adaptive control.*, *Adaptive algorithms.*, *Adaptive control theory.*, *Practical aspects of adaptive control.*, *Products and case studies.*, Universidade Federal da Paraiba, Campina Grande, Brazil. December 5–9, 1994.

Adaptive control methods: An overview., Invited paper, 5th IFAC Symposium on Adaptive Systems in Control and Signal Processing, Budapest, Hungary. June 16, 1995.

13. Seminars at the Department

Seminars presented in order of date. The seminars are given at the department during the academic year 1994–1995, 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.

Munther Dahleh (Massachusetts Institute of Technology) and **Andrej Barabanov** (St. Petersburg State University, Russia): *l_1 robust control.* Minicourse with five lectures, Aug 29 – Sep 2, 1994.

David S. Bayard (Jet Propulsion Lab, Caltech, Pasadena): *Zero annihilation methods for stable inversion of nonminimum-phase systems: Theory, applications, and adaptation methods.* July 1, 1994.

Roy Smith (Univ of California at Santa Barbara): *On the relationship between uncertain control system models and experimental data.* July 8, 1994.

Raul Savimaa (Tallinn Technical University, Estonia): Behaviour-based robots: Today the earwig, tomorrow man? July 18, 1994.

Alexander Megretski (Iowa State University): *The 'pure' mixed H_2/H_∞ optimal closed-loop system is not exponentially stable.* Aug 3, 1994.

Anders Joelsson (LTH): *Simulation of a series hybrid vehicle.* Aug 3, 1994. MSc-thesis presentation.

Peter Gruber (Landis & Gyr, Zug, Switzerland): *Real time net signal analysis based on Kalman filters.* Aug 9, 1994.

Venkat Venkatasubramanian (Purdue University): *HAZOPExpert: A knowledge-based system for HAZOP analysis.* Aug 9, 1994.

Alexander Megretski (Iowa State University): *Balanced realizations and the inverse spectral problem for self-adjoint Hankel operators.* Aug 17, 1994.

Mats Åkesson (LTH): *A comparative study of performance and properties of L/A control.* Aug 23, 1994. MSc-thesis presentation.

Sanjay Lall (Cambridge University): H_∞ *control in the time domain.* Aug 26, 1994.

Andrej Barabanov (St Petersburg Univ): *Min-max adaptive control.* Sep 6, 1994.

Tord Björsne (LTH): *Sim2ddc and Grafcet: Integration of algorithms and sequence logic.* Sep 9, 1994.

Patrik Bannura (LTH): *Program package for initiating and tuning of PID controllers.* Sep 9, 1994. MSc-thesis presentation.

Morten Hemmingsson (LTH): *Digital reglering av flexibelt servo med friktion.* Sep 12, 1994. MSc-thesis presentation.

Jerker Sjögren (LTH): *Fuzzy control of a domestic hot water system.* Sep 13, 1994. MSc-thesis presentation.

Rolf Johansson (AC): *Quadratic optimization of impedance control.* Sep 13, 1994.

Rolf Johansson and **Klas Nilsson** (AC): *Planned implementation and connections with present NUTEK projects.* Sep 13, 1994.

Albert-Jan Baerveldt and **Klas Nilsson** (AC): *Experimental robotics and real-time systems, handling parameters and excitation signals is distributed real-time systems, comments on building GUIs in Matlab4.* Sep 16, 1994.

Anders Robertsson, Rolf Johansson, Albert-Jan Baerveldt, and **Klas Nilsson** (AC): *Robotics, real-time, and system identification.* Demonstration in the Robotics Lab, Sep 16, 1994.

Anders Blomdell, Leif Andersson, Klas Nilsson (AC): *Recent developments of the real-time kernel and tools within the department. Options when implementing your algorithms.* Sep 20, 1994.

Per Anell (LTH): *Modelling of multibody systems in Omola.* Sep 20, 1994. MSc-thesis presentation.

Vladimir Droubetski (Signal Control AB): *Control of jet engines in aeroplanes in the former Sovjet.* Sep 23, 1994.

Michele Gianino (Politecnico di Torino, Italy): *Adaptive control of systems with dead zones.* Sep 23, 1994. MSc-thesis presentation.

Jörgen Olshov (LTH): *Data classification using neural networks.* Sep 30, 1994. MSc-thesis presentation.

Lennart Andersson, Mikael Johansson, Lotta Johnsson and **Anders Robertsson** (AC): *Report from 'Young Researchers Week' in Dublin.* Oct 7, 1994.

Karl Henrik Johansson (AC): *On market dependencies of agent's learning for a hyperinflation model.* Oct 2, 1994.

Mats Carlsson (LTH): *Userfriendly systems—Rapid prototyping of graphical user interface.* Oct 8, 1994. MSc-thesis presentation.

Martin Sanfridson (LTH): *Disturbances in paper machine control systems caused by nonlinear components.* Oct 18, 1994. MSc-thesis presentation.

Emanuele Carpanzano, Fabio Formenti (Milano, Italy): *Symbolic solution of linear equations in OmSim using Cramer's rule.* Oct 18, 1994.

Karl Johan Åström (AC): *The Billerud project—How minimum variance control and system identification got started.* Oct 21, 1994.

Raghunathan Rengaswamy, Dinkar Mylaraswamy (Purdue University): *An overview of process fault diagnosis.* Oct 28, 1994.

Staffan Lundgren (LTH): *Modeling and design of an HOD system.* Nov 1, 1994. MSc-thesis presentation.

Gunner Hillerström (Luleå Institute of Technology): *Robustness properties of repetitive controllers.* Nov 22, 1994.

Peter Müller (Technische Universität, Munich): *Control of systems with backlash.* Nov 22, 1994. MSc-thesis presentation.

Pertti Mäkilä (Luleå Institute of Technology): *On system identification for robust control.* Nov 24, 1994.

Per-Olof Källén (AC): *A frequency domain approach to adaptive control.* Nov 25, 1994. Doctoral dissertation defence. Opponent: Bo Wahlberg (KTH, Stockholm).

Anders Rantzer (AC): *Analysis of a system with saturation and time delay.* Nov 29, 1994.

Ulf Jönsson (AC): *Systems with uncertain parameters—Time-variations with bounded derivatives.* Nov 29, 1994.

Rolf Johansson (AC): *Multivariable system identification via continued-fraction approximation.* Dec 2, 1994.

Dinkar Mylaraswamy (Purdue University): *Steritherm diagnosis—Using ellipsoidal neural network.* Dec 13, 1994.

Per-Olof Källén (AC): *Robust pole placement design.* Dec 20, 1994.

Lars Rundqwist (Saab Military Aircraft, Linköping): *The control system in JAS 39 Gripen.* Dec 27, 1994.

Michael Rosenberg (LTH): *Nonlinear frequency control of an ultrasonic generator.* Jan 10, 1995. MSc-thesis presentation.

Walter Schaufelberger (ETH, Zürich): *Object-orientation in CACSD.* Jan 19, 1995.

Wolfgang Marquardt (RWTH, Lehrstuhl für Prozesstechnik, Aachen): *Nonlinear model-based control of semi-batch reactors with unknown reactions.* Jan 19, 1995.

Mats Andersson (AC): *Object-oriented modeling and simulation of hybrid systems.* Jan 20, 1995. Doctoral dissertation defence. Opponent: Wolfgang Marquardt (RWTH, Aachen).

Magnus Pettersson (LTH): *Dynamic process simulation of wet systems for flue gas cleaning.* Jan 25, 1995. MSc-thesis presentation.

Magnus Scherman, Martin Nyquist (LTH): *Modeling of processes in the control systems for reactor pressure, power, and feedwater in boiling water reactors.* Jan 25, 1995. MSc-thesis presentation.

Jorge Mari (KTH, Stockholm): *Analysis and optimization of certain biotechnical processes.* Jan 27, 1995.

Jonas Sonnerfeldt (LTH): *Matlab as a computer server for embedded systems—trajectory computation.* Feb 22, 1995. MSc-thesis presentation.

Jan Willems (Univ of Groningen, The Netherlands): *The logic of modelling.* March 20, 1995.

Mats Andersson, Anders Rantzer, Rolf Johansson (AC): *Three seminars on modelling.* March 20, 1995.

Jan Willems (Univ of Groningen, The Netherlands): *Controllability and observability.* March 22, 1995.

Jan Willems (Univ of Groningen, The Netherlands): *Control as interconnection.* March 23, 1995.

Jan Willems (Univ of Groningen, The Netherlands): *Modelling from data.* March 23, 1995.

Charlotta Johnsson (AC): *High-level Grafcet for supervisory sequential control.* March 27, 1995.

Torbjörn Wigren (Ericsson Radio Systems AB): *Static nonlinearities in recursive system identification.* April 5, 1995.

Olof Laurin (LTH): *Open controllers for embedded systems.* April 7, 1995. MSc-thesis presentation.

Jerker Linder (LTH): *Validation and object-oriented modelling of a transformer.* April 7, 1995. MSc-thesis presentation.

Kjell Gustafsson (Ericsson Mobile Communications AB): *Delta-sigma modulator A/D converters—A successful combination of signal processing and feedback control.* April 11, 1995.

Jonas Dyberg (Integrated Systems): *Demonstration of $MATRIX_X$.* April 12, 1995.

Marcus Nyström (LTH): *Prediction of OMX index with holographic neural networks.* April 21, 1995. MSc-thesis presentation.

Leif Andersson (AC): *Yet another LaTeX version.* April 26, 1995.

Håkan Hjalmarsson (Linköping Institute of Technology): *On iterative model free tuning of controllers.* May 3, 1995.

Vladimir Kučera (Academy of Sciences, Prague, Czech Republic): *Transfer-function equivalence of feedback/feedforward compensators.* May 4, 1995.

Anders Hansson (AC): *Stochastic control of critical processes.* May 5, 1995. Doctoral dissertation defence. Opponent: Jan H. van Schuppen (Center for Mathematics and Computer Science, Amsterdam, The Netherlands).

Karl Johan Åström (AC): *Experiences from Japan.* May 10, 1995.

Per-Olof Gutman (Technion, Haifa, Israel): *New models for backlash and gear play.* May 11, 1995.

Rudolf Kulhavy (Academy of Sciences, Prague, Czech Republic): *On recursive bayesian estimation.* May 12, 1995.

Florin Dan Barb (Delft University of Technology, The Netherlands): *A Popov theory based approach to digital H_∞ control with output measurement feedback for Pritchard Salamon Systems.* May 17, 1995.

Bo Kvarnström (Ericsson Radio): *The current status in the area of control of mobile telephone networks.* May 31, 1995.

M. Vidyasagar (Center for Artificial Intelligence and Robotics, Bangalore, India): *PAC-learning theory and generalization using neural networks.* June 7, 1995.

M. Vidyasagar (Bangalore, India): 0 – 1 *optimization using analog neural networks.* June 7, 1995.

Stefan Svensson (LTH): *Object oriented tools for adaptive control.* June 8, 1995. MSc-thesis presentation.

Rod Bell (Macquarie University, Australia): *Macro economic modelling and control—The Australian scene.* June 9, 1995.

Luis Sobral (LTH): *System identification applied to ultrasonic detection problems.* June 9, 1995. MSc-thesis presentation.

Mats Ahnelöv (LTH): *Time optimization of a solder process.* June 27, 1995. MSc-thesis presentation.

Rod Bell (Macquarie Univ, Australia) and **Karl Johan Åström** (AC): *Drum boiler modelling.* June 29, 1995.