Activity Report: Automatic Control 1992-1993

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Automatic Control

1992–1993

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Lund Institute of Technology

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1. Introduction

This report covers the activities at the Department of Automatic Control at Lund Institute of Technology (LTH) during the period 1 July 1992 – 30 June 1993, which is the academic year 1992/93. The budget for the year was 13 MSEK. This figure does not include rent for offices and laboratories.

During this period Bo Bernhardsson and Jan Eric Larsson completed their PhD theses. This brings the total number of PhDs graduating from our department to 40. Nineteen students completed their MSc degree at the department. One book, 19 journal papers or book chapters and 23 conference papers were published by staff members.

About 700 students graduated from seven courses in the civ.ing. program. There was a very high activity in the control laboratory with 339 groups of experiments. 4 PhD courses were given during the academic year.

Research has continued in established areas such as adaptive control, expert control, computer aided control engineering, robotics, and information technology.

The report is organized as follows. Economy and facilities are presented in Chapter 2. The educational activity is described in Chapter 3. Some project areas are highlighted in Chapter 4, and the dissertations completed during the year are presented in Chapter 5. A look back at our research on biotechnology is given in Chapter 6. Detailed informations about awards, theses, publications, seminars and lectures are given in the Appendices.

Acknowledgement

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Council for Engineering Sciences (TFR), the Swedish Council for Planning and Coordination of Research (FRN), the Swedish Medical Research Council (MFR), ABB, the Bo Rydin Foundation, and Sydkraft for their support to our projects.

2. Economy and Facilities

Economy

The income for the academic year 1992/93 was 13 MSEK. This does not include rent for offices and laboratories, which is paid from other accounts. The income is distributed as follows: 61% from the university, 29% from government agencies, 8% directly from industry, and 2% from software contracts and small projects.

The operating costs were: salaries 10.2 MSEK, university overhead 0.6 MSEK, and operating costs 1.7 MSEK. The operating costs cover the costs for running computers and laboratories, publishing, travel etc.

Facilities

The following computers are now available for research and education:

1	Sun4/690, 2 processors, 2.5GB disk
6	SparcStation 2 or LX with color
28	SparcStation
16	Sun3
7	PC 486
13	IBM PC/AT
8	Macintosh computers
1	Plug-in board with TI TMS320C30 signal processor
2	VME based control computers MC68030/68040
1	VME board with 6 AT&T DSP32C signal processors

The robotics lab contains the following robots

1	ABB Irb-6
1	ABB Irb-2000

with specially designed interfaces.

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 system.

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 the year the following courses were given at the department:

Course	**Number of graduated students**
Reglerteknik AK–FED (Automatic control, basic course)	286
Reglerteknik AK–M (Automatic control, basic course)	95
Processreglering (K) (Automatic process control)	102
Digital Reglering (FED) (Computer-controlled systems)	74
Datorimplementering av reglersystem (FED) (Computer implementation of control systems)	87
Processidentifiering (FED) (Process identification)	32
Adaptiv reglering (FED) (Adaptive control)	39

The course "Datorimplementering av reglersystem" has now changed its name to "Real-time Systems."

The first five courses are comparable to undergraduate courses and the last two are equivalent to graduate courses in the US system. In summary 715 students have passed courses at the department during the academic year 1992/93.

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 for one group up to eight parallel experiments, and in the elective courses we have four in parallel. There were 339 groups of students that made four-hour laboratories at the department. To handle this many groups there are many experiments in the evenings.

Master Theses

Nineteen students completed their master theses during the year. A list is given in Appendix E.

The theses concerned the following application areas: Adaptive control (2), Biomedical engineering (3), Combustion engine control (2), Fuzzy control (3), Man-machine interaction (2), Power systems (1), Process control (2), Real-time systems (2), Robotics and servomechanism (2).

Doctorate Program

Two PhD theses were completed during the period: Bo Bernhardsson (1992) and Jan Eric Larsson (1992). The abstracts of these are given in Chapter 5. This brings the total number of PhDs graduating from our department to 40. Two new PhD students (Johan Nilsson and Karl Henrik Johansson) were admitted to the department.

The following PhD courses have been given:

- Optimal Control (Ola Dahl) 5 p

- Adaptive Control (Björn Wittenmark) 6 p
- Simulation of deterministic and stochastic systems (Jan Holst, Sven Erik Mattsson) 5 p
- Linear systems (Per Hagander) 10 p

The department has recently taken the initiative to create a graduate program in Systems and Applied Mathematics at Lunds 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. A new course "Simulation of deterministic and stochastic systems," was organized by several of the departments within the program and was given for the first time during the fall of 1992.

4. Research

Research at the department concerns theory and applications. The major research areas are:

- Adaptive control
- Control theory
- Computer aided control engineering
- Applications

Adaptive Control

The research in adaptive control covers a broad area:

- Development of adaptive algorithms
- Robust adaptive control
- Automatic tuning
- Autonomous control

Frequency Domain Adaptive Control

Researchers: Per-Olof Källén and Björn Wittenmark

The certainty equivalence principle is used in most adaptive schemes. This often implies that the schemes becomes sensitive to the assumed structure of the estimated model. Too simple estimated models give poor robustness properties. To reduce problems with under-modeling without introducing large requirements on excitation, a frequency domain scheme has been investigated. The scheme gives excitational decoupling in the frequency domain and it does not rely on a parametric transfer function model of the process. This eliminates the problem of choosing appropriate process model order. Instead the process is represented by a discrete set of points on its Nyquist curve. Each frequency response point is obtained as the frequency response of a low order

parametric model estimated on band-pass filtered data. The band-pass filtering also gives frequency domain decoupling of the noise contribution to the estimation error. This reduces the process modeling noise sensitivity. Fundamental insights into the properties of the frequency domain estimator have been obtained.

The controller design is formulated as an approximation problem in the frequency domain. In the design the process is represented by the discrete set of estimated frequency response points. At each sampling instant the controller parameters are obtained as the explicit solution to a least squares problem. This gives decoupling in the frequency domain and the scheme allows for design of low order controllers for high order plants. The scheme has shown good properties when provided with reasonable closed loop specifications. Current research is directed into deeper analysis of the scheme as well as means for reducing the amount of user supplied information.

Robust Adaptive Control

Researchers: Bo Bernhardsson, Henrik Olsson, Björn Wittenmark, and Karl Johan Åström

There is a very large interest in making adaptive controllers more robust against unmodeled dynamics and parameter uncertainties. The vast literature on robust control aims mainly at designing fixed controllers that can tolerate a certain amount of uncertainty. The TFR project on Robust Adaptive Control has mainly been devoted to robust controllers. The intention is to transfer some of the results into an adaptive framework.

One promising approach is taken in Bernhardsson's PhD thesis (Chapter 5), where an identification based description of model uncertainty is connected with a robust design. The controller, which optimizes expected LQG-loss, is found using a special spectral factorization together with two standard Riccati equations. The approach is today restricted to cases where there is no signal loop around any uncertain parameter.

The department is also participating in a network within the EC program Human Capital and Mobility. The purpose with the network is

exchange of students and ideas within the broad area of nonlinear and adaptive control.

Nonlinear Adaptive Control

Researchers: Karl Johan Åström and Henrik Olsson

The goal of this project is to initiate a new research direction in nonlinear adaptive control. The project draws on our experiences in adaptive control and the striking advances in nonlinear control theory that has occurred over the past 10 years. The work is based on typical nonlinearities found in servodrives, robots, process control systems. The nonlinearities include physical phenomena such as backlash and friction but also nonlinerities that are intentionally introduced in controllers. During 1993 we have focused on control of systems with friction. A new friction model has been developed, see Canudas de Wit *et al*, 1993. This model is interesting both from a practical and a theoretical point of view. The model is simple and has interesting mathematical properties and it can also capture many of the properties observed in real systems. In this project we are also collaborating with a Human Capital and Movability Programme: Nonlinear and adaptive control: towards a design methodology for physical systems. We have also explored the application of nonlinear theory to avoid windup in controllers.

Automatic Tuning

Researchers: Karl Johan Åström, Tore Hägglund, and Per Persson

This is a continuation of earlier work. A substantial effort has been made during the year to consolidate the work. As a result of this we have been invited to write a book for ISA. During this we have also obtained significantly improved tuning rules for simple controllers. Exploratory work on tuning of multivariable systems have also been initiated. Some of the work has been done in close collaboration with industry. The PIP concept for dead time compensation has been implemented in the product ECA400 by SattControl. We have also started to explore the use of augmented PID controllers for systems with oscillatory modes. It seems possible to extend the range of application of

PID control to this domain in a way that is analogous to the dead time compensator for systems with dead time. Work has also been initiated to qualitatively characterize oscillatory systems.

Autonomous Control

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

The goal of this project is to develop the principles for design of autonomous controllers. Such controllers represent a significant increase of the automation level. They can provide diagnosis, process supervision, loop auditing in addition to normal control functions like automatic tuning, gain scheduling and adaptation. Autonomous controller use a variety of techniques, conventional control, neural networks, fuzzy control, knowledge-based systems. Two studies of suitable architectures of autonomous controller have been performed. The possibility of using neural networks for a rough characterization of system dynamics has been investigated. Several diagnosis methods have been investigated. We have also established good collaboration with the pulp and paper industry to get access to a number of realistic examples. A specific result of this work has been a new simple method for diagnosis of control loops. One version of this has been implemented in the commercial controller ECA400.

Control Theory

Linear System Theory

Researchers: Anders Rantzer, Per Hagander, and Bo Bernhardsson

This year, the research group in systems theory has been reinforced by the appointment of Anders Rantzer. The activity is focused on different aspects of *robust control* and pursued in close interaction with internationally renowned colleagues. This year, Anders and Bo have been participating in a ten month program at the Institute for Mathematics and its Applications (IMA) in Minneapolis, including nine workshops

on different aspects of control theory and countless informal discussions with other long term visitors. The research and results of this period can be summarized as follows.

Together with Li Qiu, and some other IMA visitors, Bo and Anders solved the following linear algebra problem that arises very naturally in control theory: *Given a stable real matrix A (all eigenvalues in the open left half plane), what is the smallest (induced) norm of a real matrix* Δ *such that* $A+\Delta$ *is unstable.* The paper, accepted for publication in Automatica, received enthusiastic reviews using expressions like "a milestone" and "solved an important outstanding problem".

Anders continued previous joint work with prof. A. Megretski, on synthesis of linear controllers that maximize robustness with respect to parametric uncertainty. The main result showing that this synthesis problem can be recast into convex optimization, has also gained strong international attention.

Motivated by discussions with prof. John Doyle and prof. A. Megretsky, also IMA visitors, Anders developed analysis methods for systems with uncertain time-varying parameters with bounded rate of variation. The goal is to close the current gap between stability results for constant parameters on one hand and arbitrarily fast time-variations on the other. In applications, this gap often reduces the sharpness of analysis considerably and expensive resources often need to be spent on simulations and prototype tests. Preliminary results were published at ACC in San Francisco.

Bo Bernhardsson presented his PhD-thesis in October 1992. The results of the thesis were presented at the ACC93, ECC93, and IFAC (Sydney) conferences. One of the results in the thesis concerned the so called *min-mix control* problems. This is an optimal control problem which mixes deterministic disturbances, that model worst case situations, and stochastic signals, that model average properties. The area is rich and connected to both game theory and recent results in mixed H_2 and H_∞ control.

Control of Critical Processes

Researcher: Anders Hansson and Per Hagander

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 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 research within this area covers both finding optimal feedback controllers for avoiding exceedances of critical levels, as well as design of schemes for automatic modifications of reference values based on discrete events such as alarm signals. The former approach is interesting when designing controllers for new plants or when redesigning controllers for existing plants. The latter approach is interesting when trying to improve a working installation without breaking up the existing feedback loops.

Initial results within the area of nonlinear feedback control were obtained in a master thesis project. Some results on optimal modification of reference signals have also been presented. 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 criterions 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 MU controller has also been investigated.

System Identification Theory

Researcher: Rolf Johansson

Research on several issues in system identification, especially modeling and identification of continuous-time systems, has been reported in the recently published monograph *System Modeling and Identification*. One issue penetrated in particular detail is an algorithm which fits continuous-time models to sampled data using a hybrid noise model.

Computer Aided Control Engineering

Modeling and Simulation Environments

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

The CACE project has for a number of years focused on modeling and simulation. A new object-oriented and equation-based modeling language called Omola has been developed to support modelling and reuse of models for various purposes in different applications. Models can be decomposed hierarchically with well-defined interfaces for describing interactions. All components are represented as classes. Inheritance and specialization support easy modification. Descriptions of behaviour can be given in terms of differential-algebraic equations, difference equations and elements of discrete events. The primitives for describing discrete events support events that depend on the values of the continuous time variables and allow implementation of high level descriptions such as Petri nets and Grafcet.

OmSim is an environment of tools supporting modeling and simulation of Omola models. It includes an editor for defining models graphically as a diagram of connected objects. The simulator tools include facilities for extensive analysis and manipulation to check for structural defects and for transforming the model to a representation well-suited for numerical simulation. For example, time independent variables are sorted out and constant parts of remaining equations are

evaluated. Algebraic variables are eliminated symbolically when feasible and the differential-algebraic index is reduced to one. OmSim includes well-proven numerical software, for example the numerical differential-algebraic equation solvers DASSL and DASRT with facilities to detect discrete events. OmSim also supports use of matrices of real numbers.

OmSim has been used in a couple of application projects in the areas of power systems and chemical processes. 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 currently runs on Sun-4 workstations under the X Window System. It is implemented in C++ and uses only public domain software. OmSim is available via anonymous FTP from `control.lth.se` in directory `/pub/cace`.

Object-Oriented Modeling of Chemical Processes

Researcher: Bernt Nilsson

Models are important for almost all engineering activities. This application project focus on an object-oriented methodology for development of models for complex chemical processes. Although we primarily deal with chemical processes much of the methodology can also be applied to other complex technical systems.

The main results of the work are guidelines for structure and class hierarchy decomposition. A chemical plant model is decomposed into smaller and smaller pieces following the guidelines for model structure decomposition. The libraries of predefined models are organized following the guidelines for class decomposition. These guidelines cooperate to create well defined model modules that are easy to reuse in new applications.

Other important results are particular modeling methods. Medium and machine decomposition is a method to separate the description of the process media and the processing unit machine. Methods for control system abstraction are also developed together with parameterization

methods for reusable models with complex interiors. The application project serves the purpose of applying the Omola language on a realistic modeling problem. Some modeling methods need extensions in current Omola. Examples are concepts for regular structures as well as abstract and parameterized classes.

Applications

Integrated Control and Diagnosis

Researchers: Karl-Erik Årzén and Jan Eric Larsson

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 diagnosis based on functional process models and development of visual control languages for sequential processes and batch processes. The functional modeling formalism Multi-level Flow Models (MFM) developed by Morten Lind at DTH has been used as a basis for on-line measurement validation, alarm analysis, and fault diagnosis. This work has led to a PhD thesis of Jan Eric Larsson. The methods have been implemented as a toolbox in G2.

The work on languages for sequential processes uses object-oriented extensions of the Grafcet sequential function chart formalism. The system allows an integration of sequence control and monitoring and diagnosis. The work has led to a commercial product, Grafchart, that is currently in on-line operation in a US refinery.

Fuzzy Control

Researchers: Anders Hansson and Karl-Erik Årzén

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. A practical result in this area is the comparison between conventional control and fuzzy control on different processes carried out as a master thesis project. A theoretical result in this area is a stochastic interpretation of the membership functions of fuzzy logic.

Within the area of applications the design of anti-windup schemes for PID controllers has been investigated. A similar scheme has in corporation with Landis & Gyr AG been designed for their heating controller Sigmagyr RVP110. Another application is a fuzzy control toolbox which has been derived for the real-time expert system tool G2.

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 working group started in October 1992 and has a duration of 36 months. The first project meeting was held in Albi, France in March 1992. The coordinator for the project is ELITE – European Laboratory for Intelligent Techniques Engineering in Aachen and the partners consist of eight universities and one industry which all are internationally well known in the fuzzy control field.

Robotics

Researchers: Klas Nilsson, Ola Dahl, and Rolf Johansson

The robotics and sensory control laboratory has been centered around an ABB Irb-6 robot. It now also includes an ABB Irb-2000 robot. Hard-

ware 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 main research project has been path following. The goal is to have efficient specification and generation of fast robot motions along a geometric path when the motion is limited by torque constraints. Typical applications are gluing, arc welding, and laser cutting. A feedback scheme for path following by trajectory time-scaling has been developed and tested experimentally. A key idea is that a scalar quantity, the path acceleration, is modified by a secondary control loop, resulting in coordinated adjustment of the individual joint motions.

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 ongoing.

Fast Adaptive Control

Researcher: Karl Johan Åström

An adaptive controller capable of running at sampling rates of several kHz has been implemented on a dual processor system based on a Macintosh with a digital signal processor. A real time kernel has been written for the DSP and a flexible man-machine interface has been implemented using LabView. The system has been used for control of high performance servosystems in a mechatronics project. We expect this project to be completed during the next academic year. Significant contributions to the project have been given by students in our courses on Adaptive Control and Real-Time Systems.

Real-Time Control

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

Real-time control has a long tradition at the department both as a research area and in teaching. In our laboratory courses we use two computer environments: PC-486 compatibles and Sun workstations connected to VME 68020 processors. A real-time kernel written in Modula-2 has been developed for both these environments. Prototype ports for use with C and C++ have been made. A version integrating C, C++, and Modula-2 is planned, as well as a port to Sun Solaris. A real-time kernel for the TI signal processor TMS320C30 has also been developed. It is used with Macintosh computers, and includes a graphical interface based on the LabView software from National Instruments.

In real-time systems, robot control is used as a typical demanding application. The work in real-time control also has connections to the work on Grafcet in the Integrated Control and Diagnosis project. Here G2 is used as the platform for development of object-oriented graphical languages based on Petri net ideas and with applications in real-time control and supervision. In the Autonomous Control project an interface between G2 on Sun and the VME systems is being developed.

Collaboration with the Pulp and Paper Industry

Researcher: Tore Hägglund

With support from the Bo Rydin foundation we have initiated a project, where the goal is to establish a closer collaboration with the pulp and paper industry. The idea is to investigate what kind of control problems that is of most interest for the pulp and paper industry, and to make field tests of our new research results.

The project started at the beginning of 1993. Since then, we have been in contact with several pulp and paper companies. Together with Stora Teknik AB, we have made field tests of a new dead-time compensating controller as well as a method for automatic supervision of control loop performance.

Power Systems

Researcher: Karl Johan Åström

The investigation in power systems is a cooperation with Sydkraft AB. Thermal units in power systems are modeled using the Omola language developed within the CACE project. The purpose is to collect models of different parts of the total system. Omola models have been developed for boilers and superheaters. The models can be used for design, simulation, and documentation.

Modeling and Control in Medical Systems

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

One project treats the estimation of parameters and modeling of human postural dynamics. The work is sponsored by the Swedish Medical Research Council (MFR) and the Söderberg Foundation. Stability is investigated by means of galvanic and vibration-induced perturbations with application of methods from control theory and signal processing. The goal is to find diagnostic parameters that describe the human ability to maintain posture. The methods developed are intended for use in diagnosis and rehabilitation of human balance disorders.

Control of Biotechnology Processes

Researchers: Per Hagander in cooperation with Bo Mathiasson and Olle Holst (Department of Biotechnology)

The bacteria *Pseudomonas Cepacia* is grown on the toxic substrate salicylate to produce the enzyme salicylate hydroxylase, used in clinical chemistry to determine salicylate in blood samples. A spectrophotometric sensor is developed, and experiments are performed using PI-control around a basic substrate flow scheme. The growth rate is quite high provided that a high oxygen concentration can be maintained. A new regulator with an unstable load model is also successfully tested. Preliminary experiments have started with a genetically engineered organism.

Advanced Engine Control for Ultra-Low Emissions

Researchers: Karl Johan Åström and Rolf Johansson in cooperation with Gunnar Lundholm and Per Tunestål (Div. Combustion Engines)

In the Co-Nordic Gas Bus Project two city bus engines were adapted for low-emission duty with natural gas. One of them, a Scania DS11 was adapted by Ricardo in England and this engine is now at the Combustion Engines Division at Lund Institute of Technology. A research project concerning modeling and control of air/fuel ratio with the purpose of ultra-low emissions has been started in cooperation with the Department of Automatic Control.

Rolling Mill Control

Researcher: Lars Malcolm Pedersen and Björn Wittenmark

The subject of the project is improvement of the thickness tolerances of the plates rolled by the plate mill at The Danish Steelworks Ltd. (DDS) in Frederiksværk, Denmark. The improvement of the thickness accuracy will be obtained by designing a better controller for the process. The project includes literature study, development of a dynamical model, and design of suitable controller for the process. Lars Malcolm Pedersen is an employee of DDS. He works both at the Steelwork and at the Department of Automatic Control. The project is supported financially by DDS and The Nordic Fund for Technology and Industrial Development.

5. Dissertations

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

Topics in Digital and Robust Control of Linear Systems

Bo Bernhardsson
PhD dissertation, 27 October 1992

This thesis deals with several problems in the theory of linear systems. It consists of an introduction and six papers.

Paper I solves the problem of obtaining a finite dimensional sampled representation of a continuous time, state-space system with several time delays. Necessary and sufficient conditions for existence of a finite dimensional sampled system are given. A short algorithm for computing the sampled system is given. Paper II presents existence conditions for so called pure-mixed saddle equilibria. These conditions give insight into the properties of min-max controllers used in H_∞-control theory and stochastic differential games. Paper III analyzes a mixed H_2/H_∞-control problem. It is shown how recent results in this field can be obtained using standard differential game theory and a recently presented separation theorem due to Pierre Bernhard. The problem is solved by completion of squares. The time-varying, finite time horizon problem is solved. An explicit formula for the value of the game is obtained. New formulas for the discrete time case are given. A simple but rich example illustrates the equations. Paper IV presents a dual relationship between two special problem classes; a question that has been discussed previously by other authors. It is shown that duality can be obtained if generalized problem formulations including dynamic

weighting functions are used. The result is illustrated by a derivation of a polynomial solution to the frequency-weighted discrete-time multivariable LQG feedforward control problem. Paper V discusses the concept of strong stabilization. The paper points out several weaknesses of the present concept. Paper VI describes how information from standard system identification can be used to find robust performance controllers. The expected value of the H_2-norm of the closed loop system is minimized by rewriting the problems as an LQG-problem for an extended problem.

Knowledge-Based Methods for Control Systems

Jan Eric Larsson
PhD dissertation, 11 December 1992

This thesis consists of three projects which combine artificial intelligence and control.

The first part describes an expert system interface for system identification, using the interactive identification program Idpac. The interface works as an intelligent help system, using the command spy strategy. It contains a multitude of help system ideas. The concept of *scripts* is introduced as a data structure used to describe the procedural part of the knowledge in the interface. Production rules are used to represent diagnostic knowledge. A small knowledge database of scripts and rules has been developed and an example run is shown.

The second part describes an expert system for frequency response analysis. This is one of the oldest and most widely used methods to determine the dynamics of a stable linear system. Though quite simple, it requires knowledge and experience of the user, in order to produce reliable results. The expert system is designed to help the user in performing the analysis. It checks whether the system is linear, finds

the frequency and amplitude ranges, verifies the results, and, if errors should occur, tries to give explanations and remedies for them.

The third part describes three diagnostic methods for use with industrial processes. They are *measurement validation,* i.e., consistency checking of sensor and measurement values using any redundancy of instrumentation; *alarm analysis,* i.e., analysis of multiple alarm situations to find which alarms are directly connected to primary faults and which alarms are consequential effects of the primary ones; and *fault diagnosis,* i.e., a search for the causes of and remedies for faults. The three methods use *multilevel flow models,* (MFM), to describe the target process. They have been implemented in the programming tool G2, and successfully tested on two small processes.

6. Looking Back

Biotechnology

It has become a tradition that we under this title give some perspective on one of our research areas. It is interesting to present why and how our activities started, how the research was performed, and what we now consider as the major achievements. It is also important to evaluate the industrial impact of the research, and when doing so it should be done with a reasonable time perspective.

Our biotechnology work started in 1981 when Jan Peter Axelsson decided to do an MSc-thesis on continuous ethanol production using immobilized yeast-cells. Jan Peter Axelsson became together with Per Hagander our main researcher in this field. The work was supported by two three-year contracts from STU.

Biotechnology was at that time emerging as the field of the future. Seed companies were founded around major universities in the US. The field would easily attract good PhD-students. We were watching the development and saw that dynamical models and simulation would be useful tools. Lars Nielsen had made his MSc-thesis, "Control of the ATP-synthesis in mitochondria" (1979), with Per Hagander and Håkan Wennerström (Chemical Center) as supervisors, and Gustav Olsson was, since 1973, heading a project "Control of waste water treatment plants". We were also involved in medical applications. Per Hagander was cosupervisor for PhD-students at the medical faculty and at the pharmaceutical company Pharmacia. A collaboration had started with the company Gambro in Lund producing artificial kidneys, and we were involved in their development of a continuous glucose sensor.

The sensor development at the department of Applied Biochemistry became the foundation for our work on feed-back control of biotechnical processes. Bo Mattiasson, Bengt Danielsson, Klaus Mossbach and

coworkers had worked on the enzyme thermistor and its applications. A PhD-student Carl Fredrik Mandenius used this biosensor to measure sucrose for feedback control of continuous ethanol production. There were problems with oscillations, but the productivity of the process was increased.

Jan Peter Axelsson in his MSc-work (1982) found that the sensor time-lag limited the possible feedback-gain, and pump nonlinearities caused substantial differences in local gain. Computer control was implemented using one of our laboratory LSI-11 computers. A simple operators interface was developed as well as facilities for data-logging. The programming was done in Pascal using modules developed for our real-time control course. Several different types of regulators were tested including dead-time compensation by a Kalman filter and gain-scheduling. The results were presented at the 1st IFAC Workshop on Modelling and Control of Biotechnical Processes in 1982. Carl Fredrik Mandenius continued the work on biosensors, and he constructed a membrane-gas sensor-system for ethanol in the fermentor medium based on a semiconductor device.

Our work was successful, and it made us think about a more formal collaboration. We investigated the interest from industries like Alfa-Laval, Satt Control, and the Swedish Sugar Company, and then we decided to make a research proposal to STU. Jan Peter Axelsson was accepted as a PhD-student to work on the project.

The project was funded by STU in Feb 1983, for the two departments in total 1.2 MSEK over three years. STU suggested that we made contact with the Swedish Yeast Company. Thus we started to investigate if the ethanol sensor system could be used to control the substrate feedrate in fedbatch production of bakers' yeast. State of the art in research was to use exhaust-gas measurements to indirectly estimate the characteristic variables of the process using various types of nonlinear filters. It seemed difficult to get reproducible data.

At about that time Bo Mattiasson was appointed professor of Biotechnology, a new department at the Chemical Center. This was the start of a remarkable expansion. The biotechnology specialization of the

chemical engineering curriculum began, and a special automatic control course was introduced around our research project. The course was not continued when our Process Control course became mandatory for all the chemical engineering students.

Bo Mattiasson also supervised a PhD at the department of Applied Microbiology, Olle Holst (1985), on improved oxygenation of immobilized cells. Two MSc-theses in Automatic Control, Olsson (1983) and Troedsson, Mauritzson (1985) were written during that work. Olle Holst later joined the Biotechnology department, where he is currently lecturer. He is also reponsible for the fermentation pilot plant, and he is the main contact for control applications.

Another collaboration with the department of Applied Microbiology was the MSc-thesis by Bernt Nilsson (1984) "Enzymatic hydrolysis of cellulose in two-phase system". The work was supervised by C-F Mandenius, Bärbel Hahn-Hägerdahl, and Per Hagander. Bernt Nilsson later joined the Automatic Control department for a PhD-thesis, "Object-Oriented Modeling of Chemical Processes".

During the first year of the STU-contract we continued experiments with a continuous stirred tank reactor (CSTR) now in series with a packed bed reactor, while the new equipment was purchased and installed. These experiments were combined with further biosensor development to the PhD-thesis by Mandenius (1985). Nonlinearities made the controller tuning difficult. The data was later analyzed by Axelsson in his thesis (1989). The work was also presented at the AIChE meeting in 1989 and at the 1990 CDC. For a general CSTR with immobilized cells it was demonstrated that the controller gain should have different sign for small and large disturbances. A very simple second order bilinear model was shown to describe the system, and a control theoretical analysis was possible using reachable sets.

The bakers' yeast production work started off with an MSc-thesis by Brånhult (1985) investigating a Japanese model of the glucose-ethanol-celldensity-dynamics. A high substrate concentration is required to get a fast growth, but too much substrate results in ethanol production. This decreases the yield, and high concentrations of this byproduct

actually also inhibits the growth. Simulations were made of different control strategies, and there were indications that PID-regulators would not be sufficient.

Turn-key process control systems were at this time much too expensive for our budget, and the LSI-11 system was therefore copied and slightly extended to include facilities for calibration etc. When the fermentor was installed, we started to accumulate our own data. The first presentations were made at the 3rd European Congress of Biotechnology (1984) and the 1st IFAC Symposium on Modelling and Control of Biotechnology Processes (1985). A new model was developed from mass-balance equations combined with parameters obtained by simple experiments. Different disturbances were simulated, and it was found essential to make the sensor as fast as possible to get good feed-back control. It was then possible to use a properly tuned PID-control around a basic dosage scheme.

The model was used to design identification experiments, and it was found suitable to keep the regulator going during the experiments. Identification was thus performed in closed loop for the first time on this type of process. The experiments were remarkably reproducible, and a time-variability predicted from the model was confirmed. The gain changed less than 50 % but the time constant changed a factor of at least 10. The main control problem was the increasing substrate demand, which could be regarded as an exponential load disturbance. It was further found both in simulations and in experiments that a design for robust control gave satisfactory performance, and there was no need for any scheduling.

During the project the ethanol sensor was also successfully tested for about one year at the Swedish Yeast Company. Another test was done at the Swedish pulp and paper industry MoDo in one of their ethanol production units.

In Oct 1986 STU funded a second three year period (in total 1.2 MSEK). The yeast process was to be phased out after one year. Axelsson continued analyzing the accumulated experiments, and he refined the models using stoichiometric results from ETH, Switzerland. He formulated in

his thesis a model of how the different metabolic states depend on the respiratory capacity using a bottle-neck concept, and he also suggested a new modified PID-like controller to accomodate for exponential disturbances instead of step disturbances. An unstable pole, corresponding to the growth rate, was used instead of the integrator. The results were presented at the IFAC World Congress in 1990, where adaptation with respect to the growth rate was also introduced.

Studies on a new model system were started. The bacteria *Pseudomonas Cepacia* was grown on the substrate salicylate. In their metabolism the bacteria use an enzyme that could be interesting in clinical chemistry for analyses of the blood salicylate concentration. The substrate is inhibitory for both enzyme production and growth at rather low concentrations. Feed-back control is critical. A sensor system using a cell separation filter and a spectrophotometer was developed. Three MSc-projects resulted, Sjövall (1989), Hoff (1990), and Sandin, Ström-Olsen (1991). Anne Hoff was a Dutch student doing her project work at the Biotechnology department. A biotechnology PhD-student, Anita Tocaj continued the work, and the work was published both at conferences and in biotechnology journals.

When we got the process under control, it was found that the inhibitory effects could be avoided easily. Then it was possible to optimize with respect to nitrogen and oxygen supply. The obtained growth rate was so high that we could have problems with the oxygen supply. Side-reactions started that might interact with the sensor signal. We actually started to use pure oxygen as a supplement. The growth-rate dependence of the substrate was in the saturated region. The modified PID-controller was tested and showed a much better ability to maintain the desired substrate concentration at high cell desities.

Our activities are now centered around genetically engineered *E. coli*. Contacts are in progress with different groups at Kabi Pharmacia.

Academic and Industrial Impact

Three PhD-theses have come out of our collaboration together with several MSc's. The work is presented at many conferences and in a

number of journal papers. Axelsson's thesis is freqently cited also in textbooks.

The industrial impact is both direct and indirect. A seed company was founded around the ethanol sensor, and Kabi Pharmacia is now using it in their yeast processes. Axelsson and Mandenius were both employed by Kabi Pharmacia, and they could directly transfer their knowledge.

It was possible to directly apply the sensor and the control algorithms to the production of growth-factors using genetically engineered yeast. The controller parameters could actually be chosen by simple scaling based on parameter values of a model of the process. Reproducibility and product yield was enhanced. Before the ethanol control was installed, difficulties were often believed to be caused by ethanol production. It therefore became possible to start a more systematic process optimization. For a new process, feedback control would be of special value when different strains and media are tested in the laboratory, and when there is a lot of uncertainty about reasonable substrate profiles. The fact that we during our projects always looked for the simplest possible solutions to the control problems, has facilitated the technology transfer to industry. It should be remembered that the industrial laboratories sometimes have the highest competence.

The indirect impact is through the PhD-education. Pharmacia are now trying to recruit more PhDs with this background in biotechnology, control, and dynamical systems. The interdisciplinary work is a good training for industrial development organized in projects, and it improves your problem-solving abilities when you have to explain your ideas to colleagues from another dicipline. It is however important to maintain a common base in automatic control for all our PhDs. It could also be mentioned that two other PhDs from our department currently deliver integrated process control systems for the fermentation industry, Krister Mårtensson at MIC and Lars Pernebo at SattControl.

Without the long term support by STU, now NUTEK, this research would never have been done. The support and the encouragement is gratefully acknowledged.

A. Personnel and Visitors

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`

During the year the following persons have been employed at the department. The list shows the status of June 1993 if nothing else is mentioned.

Professors

Karl Johan Åström
Björn Wittenmark

Associate Professors

Per Hagander
Tore Hägglund
Rolf Johansson

Research Associates

Karl-Erik Årzén
Ola Dahl
Kjell Gustafsson (until Sep 1, 1992)
Anders Rantzer (from Nov 1, 1992, on leave)
Sven Erik Mattsson
Per Persson (until Jan 1, 1993)

Research Engineers

Leif Andersson
Anders Blomdell
Rolf Braun
Dag Brück
Tomas Schönthal

PhD Students

Mats Andersson
Bo Bernhardsson (until Nov 1, 1992)
Anders Hansson
Karl Henrik Johansson
Ulf Jönsson
Per-Olof Källén
Jan Eric Larsson
Jörgen Malmborg
Bernt Nilsson
Johan Nilsson
Klas Nilsson
Henrik Olsson
Anders Wallén (previous Nilsson)

Secretaries

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

Visiting Scientists

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

Mr Antoni Guasch
Universitat Politécnica de Catalunya, Barcelona, Spain
(2–9 September 1992)

Prof Carlos Canudas de Wit
ENSIEG, Grenoble, France
(9–13 November 1992)

Prof C. C. Hang
National University of Singapore
(16 November – 30 December 1992)

Prof Paul Fishwick
Dept of Computer and Information Sciences
University of Florida, Gainesville, Florida
(14–25 June 1993)

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

Dr Tim Berg University of Oxford, UK
(From 25 January 1993)

Mr Michel Colombo
ENSIEG, Grenoble, France
(19 April – 10 September 1993)

Special Visits

On September 10, 1992, a group of 11 professors from St Petersburg and Moscow, Russia, visited the department in connection to the Swedish-Russian Control Conference in Linköping.

On October 15, 1992, a group of 37 members of Blekinge Tekniska Förening (an engineering association) visited the department.

B. Awards

Mats Andersson received the Saab-Scania Scholarship in April 1993.

The IEEE Medal of Honor

The Medal of Honor is the oldest and most prestigous award bestowed by the IEEE. The Medal is given only when a candidate has made a singular and exceptional contribution to the science and technology of interest to the IEEE. The award consists of a gold medal, a bronze replica, $20 000, and a certificate, and is supported by the Frank A. Cowan Fund and the IEEE Foundation, Inc.

While nominations for the Medal of Honor are accepted on a yearly basis, it is not necessarily an annual award. In the past 74 years, the Medal has been awarded only 70 times. A total of four members of the Control Systems Society have received the award.

Originally established by the Institute of Radio Engineers to acknowledge distinguished service to the field of radio communications, the Medal of Honor was first awarded to Major Edwin H. Armstrong in 1917. The award evolved to become the highest honor in the field of radio engineering, given to individuals of outstanding technical achievement and standing. In 1963, the scope of the award was broadened to cover all of electrical and electronics engineering, following the merger of the IRE and the American Institute of Electrical Engineers to form the IEEE.

Previous winners of the IEEE Medal of Honor in the field of Automatic Control are: Harry Nyquist (1960), Rudolf Emil Kalman (1974), and Richard Bellmann (1979).

The medal was awarded to **Karl Johan Åström** for "fundamental contributions to theory and applications of adaptive control technology" on February 27, 1993.

C. External Assignments

Member of Advisory Committees and Working Groups

Karl-Erik Årzén. Member of IFAC Technical Committee on Computers. Member of IFAC Technical Committee on Applications, Working Group on Chemical Process Control.

Karl Johan Åström. Member of Research Advisory Council for the Engineering Research Center, Insitute for Systems Research, University of Maryland. Member of Research Advisory Council, Laboratory for Information and Decision Systems, MIT. Member of IFAC Technical Committee on Theory Control.

Per Hagander. Member of IFAC Technical Committee on Biomedical Engineering Control (TC-BIOMED).

Tore Hägglund. Member of IFAC Technical Committee on Applications.

Björn Wittenmark. Member of IFAC Technical Committee on Applications.

Board Member

Karl Johan Åström. Vice president of the Royal Swedish Academy of Sciences (IVA).

Björn Wittenmark. Member of Board of Governors of IEEE Control System Society. Chairperson of the Committee for Equal Opportunities at University of Lund, Sweden.

Book and Journal Editor

Karl-Erik Årzén. Associate editor of Automatica.

Karl Johan Åström. Member of Editorial advisory board for Systems and Control Encyclopedia. Editor of Automatica and International

Journal of Adaptive Control and Signal Processing. Member of editorial board of International Journal on Control. Member of Advisory Board for the IEEE Transactions on Control Systems Technology. Associate editor of Progress in Systems and Control Theory.

Björn Wittenmark. Associate editor of Automatica and International Journal of Adaptive Control and Signal Processing, member of editorial board of Journal of Forecasting.

Member of International Program Committee (IPC)

Karl Johan Åström. Member of IPC for IFAC Symposium on Adaptive Systems in Control and Signal Processing, July 1992. Member of IPC for IEEE Mediterranean Symposium on New Directions in Control Theory and Applications, June 1993.

Anders Rantzer. Member of the editorial board for IEEE Conference of Decision and Control (CDC) 1993.

Björn Wittenmark. Member of IPC for IFAC Symposium on Adaptive Systems in Control and Signal Processing, July 1992.

Opponent and Member of Examination Committee

Tore Hägglund. External examiner of the thesis by A. M. Mota, University of Aveiro, Portugal, March 1993.

Björn Wittenmark. Member of examination committee of the thesis by Anders Holtsberg, Department of Mathematical Statistics, LTH, February 1993. External reviewer for a professorship in Automatic Control, Luleå Institute of Technology, Sweden.

D. External Publications

Books

Johansson, Rolf: *System Modeling and Identification.* Prentice Hall, Englewood Cliffs, New Jersey, 1993.

Papers

Årzén, Karl-Erik: "Expert control – Intelligent tuning of PID controllers." In Tzafestas, Ed., *Applied Control: Current Trends and Modern Methodologies.* Marcel Dekker Inc, 1993.

Åström, Karl Johan: "Autonomous control." In Bensoussan and Verjus, Eds., *Future Tendencies in Computer Science, Control and Applied Mathematics*, volume 653 of *Lecture Notes in Computer Science*, pp. 267–278. Springer-Verlag, 1992.

Åström, Karl Johan: "Evaluation of quadratic loss functions for linear systems." In Jamshidi *et al.*, Eds., *Fundamentals of Discrete-Time Systems – A Tribute to Professor Eliahu I. Jury*, pp. 45–56, Albuquerque, New Mexico, 1993. TSI Press.

Åström, Karl Johan, and Karl-Erik Årzén: "Expert control." In Antsaklis and Passino, Eds., *An Introduction to Intelligent and Autonomous Control*, pp. 163–189. Kluwer Academic Publishers, 1993.

Åström, Karl Johan, and Michael Lundh: "Lund control program combines theory with hands-on experience." *IEEE Control Systems Magazine*, **12:3**, pp. 22–30, 1992.

Åström, Karl Johan, and Thomas J. McAvoy: "Intelligent control." *Journal of Process Control*, **2:2**, pp. 1–13, 1992.

Åström, Karl Johan, and Thomas J. McAvoy: "Intelligent control." In White and Sofge, Eds., *Handbook of Intelligent Control*, New York, 1993. Van Nostrand.

Bernhardsson, Bo, and M. Sternad: "Feedforward control is dual to

deconvolution." *International Journal of Control*, **57:2**, pp. 393–405, 1993.

Hagander, Per: "Comment on 'Conditions for stable zeros of sampled systems'." *IEEE Transactions on Automatic Control*, **38:5**, p. 830, 1993.

Hang, C. C., Karl Johan Åström, and W. K. Ho: "Relay auto-tuning in the presence of static load disturbance." *Automatica*, **29:2**, pp. 563–564, 1993.

Hansson, Anders: "Control of level-crossings in stationary gaussian random processes." *IEEE Transactions on Automatic Control*, **38:2**, pp. 318–321, 1993.

Larsson, Jan Eric: "Kan Searle tänka?," (Can Searle think?). *Filosofisk Tidskrift (Swedish Philosophical Journal)*, 1992.

Lilja, Mats, and Karl Johan Åström: "Approximate pole placement approach." *Journal of Guidance, Control, and Dynamics*, **15:5**, pp. 1082–1086, 1992.

Magnusson, Måns, and Rolf Johansson: "Dynamic properties of feedback control of human posture in subjects with vestibular neuritis." *Acta Otolaryngol*, **503**, pp. 47–48, 1993.

Mattsson, Sven Erik, and Mats Andersson: "Omola – An object-oriented modeling language." In Jamshidi and Herget, Eds., *Recent Advances in Computer Aided Control Systems Engineering*, volume 9 of *Studies in Automation and Control*, pp. 291–310. Elsevier Science Publishers, 1993.

Mattsson, Sven Erik, Mats Andersson, and Karl Johan Åström: "Object-oriented modelling and simulation." In Linkens, Ed., *CAD for Control Systems*, chapter 2, pp. 31–69. Marcel Dekker Inc, New York, 1993.

Mattsson, Sven Erik, and Gustaf Söderlind: "Index reduction in differential-algebraic equations." *SIAM Journal of Scientific and Statistical Computing*, **14:3**, pp. 677–692, 1993.

Rantzer, Anders: "A weak Kharitonov theorem holds if and only if the stability region and its reciprocal are convex." *Int. Journal of Robust and Nonlinear Control*, **3**, pp. 55–62, 1993.

Tocaj, Anita, Anne Hof, Per Hagander, and Olle Holst: "Fed-batch cultivation of *pseudomonas cepacia* with on-line control of the toxic substrate salicylate." *Appl. Microbiol. Biotechnol.*, **38**, pp. 463–466, 1993.

Conference Papers

Årzén, Karl-Erik: "Intelligent process control." In *INTERKAMA Congress*, Düsseldorf, Germany, 1992. Invited paper.

Åström, Karl Johan: "Adaptive control—Past, present and future." In *Conference Proceedings – May 24–28, 1993. LAAS-CNRS 25th Anniversary*, pp. 115–127, Toulouse, France, 1993. Invited paper.

Åström, Karl Johan: "Intelligent tuning." In *Proceedings of IFAC 4th International Symposium on Adaptive Systems in Control and Signal Processing, Grenoble 1992.* Pergamon Press, 1993. Invited Plenary Paper.

Åström, Karl Johan: "Matching criteria for control and identification." In *Preprints European Control Conference, ECC '93*, Groningen, The Netherlands, June 1993.

Åström, Karl Johan, Tore Hägglund, C. C. Hang, and W. K. Ho: "Automatic tuning and adaptation for PID controllers – A survey." In *Preprints 4th IFAC Symposium on Adaptive Systems in Control and Signal Processing*, pp. 121–126, Grenoble, July 1992. Invited paper.

Åström, Karl Johan, Tore Hägglund, and Anders Wallenborg: "Automatic tuning of a digital controller." In *Preprints 4th IFAC Symposium on Adaptive Systems in Control and Signal Processing*, pp. 445–450, Grenoble, July 1992.

Bernhardsson, Bo, and Per Hagander: "A stochastic differential games approach to mixed H_2/H_∞-control." In *American Control Conference*, pp. 236–237, San Francisco, California, 1993.

Canudas de Wit, C., Henrik Olsson, Karl Johan Åström, and P. Lischinsky: "Dynamic friction models and control design." In *Proceedings of the 1993 American Control Conference*, pp. 1920–1926, San Francisco, California, 1993.

Dahl, Ola: "Path constrained motion optimization for rigid and flexible joint robots." In *Proceedings of the 1993 IEEE International Conference on Robotics and Automation*, Atlanta, Georgia, May 1993.

Dahl, Ola: "Path constrained robot control with limited torques – experimental evaluation." In *Proceedings of the 1993 IEEE International Conference on Robotics and Automation*, Atlanta, Georgia, May 1993.

Hagander, Per, and Bo Bernhardsson: "Min-mix control in discrete time by completion of squares." In *Preprints European Control Conference, ECC'93*, pp. 2048–2051, Groningen, The Netherlands, June 1993.

Hägglund, Tore: "Disturbance supervision in feedback loops." In *Preprints Tooldiag'93, International Conference on Fault Diagnosis*, Toulouse, France, April 1993.

Johansson, Rolf: "Identification of continuous-time models." In *Proc. 31st IEEE Conference on Decision and Control*, pp. 50–55, Tucson, Arizona, December 1992.

Johansson, Rolf: "Supermartingale analysis of mimimum variance adaptive control." In *Preprints 4th IFAC Symposium on Adaptive Systems in Control and Signal Processing*, pp. 521–526, Grenoble, July 1992.

Larsson, Jan Eric: "Diagnosis with explicit models of goals and functions." In *ITM/NUTEK Seminar on Complex Systems*, KTH/EKC, Stockholm, Sweden, 1993.

Larsson, Jan Eric: "Diagnostic reasoning with MFM." In *Proceedings of the Workshop on Modeling Problems in Control and Supervision of Complex Dynamic Systems*, Lyngby, Denmark, 1993.

Lundh, Michael, and Karl Johan Åström: "Automatic initialization of robust adaptive controllers." In *Preprints 4th IFAC Symposium on Adaptive Systems in Control and Signal Processing*, pp. 439–444, Grenoble, July 1992.

Mattsson, Sven Erik: "Towards a new standard for modelling and simulation tools." In Iversen, Ed., *SIMS'93, Applied Simulation in Industry — Proceedings of the 35th SIMS Simulation Conference*, pp. 1–10, Trondheim, Norway, June 1993. SIMS, Scandinavian Simulation Society, c/o SINTEF Automatic Control. Invited paper.

Mattsson, Sven Erik, and Mats Andersson: "Omola—An object-oriented modelling language." In *Colloquium on Open systems: The Way Forward in Computer Aided Control Engineering*, The Institution of Electrical Engineers, London, UK, December 1992. Invited paper.

Nilsson, Klas: "On the integration of on-line and off-line robot programming." In *Proceedings from 'Robotikdagar'*, Linköping, Sweden, June 1993.

Nilsson, Klas, and Lars Nielsen: "Issues in manipulator programming." In *Computer Science at Swedish Universities.* Swedish National Board for Industrial and Technical Development (NUTEK), 1992.

Nilsson, Klas, and Lars Nielsen: "On the programming and control of industrial robots." In *International Workshop on Mechatronical Computer Systems for Perception and Action*, pp. 347–357, Halmstad, Sweden, 1993.

Persson, Per, and Karl Johan Åström: "Dominant pole design—A unified view of PID controller tuning." In *Preprints 4th IFAC Symposium on Adaptive Systems in Control and Signal Processing*, pp. 127–132, Grenoble, France, July 1992.

Rantzer, Anders: "Uncertainties with bounded rates of variation." In *Proceedings of American Control Conference*, San Francisco, California, 1993.

Wittenmark, Björn: "Adaptive control of a stochastic nonlinear system: An example." In *2nd Workshop on Adaptive Control: Applications to Nonlinear Control and Robotics*, Cancun, Mexico, December 1992.

Wittenmark, Björn: "Computational aspects of adaptive control." In *IFAC Workshop on Mutual Impact of Computing Power and Control Theory*, Prague, Czechoslovakia, September 1992. Plenary talk.

Technical Reports

Hörmander, Lars, and Bo Bernhardsson: "An extension of Bohr's inequality." Report 1992:9, Department of Mathematics, Lund Institute of Technology, Lund, Sweden, August 1992.

E. Reports

Dissertations

Bernhardsson, Bo: *Topics in Digital and Robust Control of Linear Systems.* PhD thesis ISRN LUTFD2/TFRT--1039--SE, September 1992.

Larsson, Jan Eric: *Knowledge-Based Methods for Control Systems.* PhD thesis ISRN LUTFD2/TFRT--1040--SE, November 1992.

Final Reports

Årzén, Karl-Erik: "A model-based control system concept." Report ISRN LUTFD2/TFRT--3213--SE, December 1992.

Dagnegård, Eva, and Björn Wittenmark: "Activity report 1991–1992." Report ISRN LUTFD2/TFRT--4020--SE, November 1992.

Master Theses

Akhtar, Imran: "Galvanisk balansstimulator," (Galvanic balance stimulator). Master thesis ISRN LUTFD2/TFRT--5471--SE, April 1993.

Carlsson, Anders: "Liten, snabb realtidskärna i C," (A small, fast real-time kernel in C implementation for DSP with example). Master thesis ISRN LUTFD2/TFRT--5469--SE, May 1993.

Engelin, Lars: "Objektorienterad implementering för signalprocessor av motorstyrning och givaravläsning," (Object-oriented implementation for signal processors of motor control and sensor readings). Master thesis ISRN LUTFD2/TFRT--5472--SE, June 1993.

Eriksson, Magnus: "Styrning av missil med hjälp av multimodellering," (Controlling a missile by use of multimodelling). Master thesis ISRN LUTFD2/TFRT--5463--SE, October 1992.

Höglund, Gunilla, and Johan Lidman: "Mätning och identifiering av postural reglering," (Measurement and identification of postural

control). Master thesis ISRN LUTFD2/TFRT--5464--SE, October 1992.

Idofsson, Thomas, and Mats Wennberg: "Varvtalsreglering av en förbränningsmotor," (Speed control of an internal-combustion engine). Master thesis ISRN LUTFD2/TFRT--5465--SE, December 1992.

Johansson, Magnus: "Modell av strömriktare i SIMULINK," (Model of a DC-converter in SIMULINK). Master thesis ISRN LUTFD2/TFRT--5466--SE, December 1992.

Lu Jimmy, C. M.: "Flight operations support system for X11/MOTIF." Master thesis ISRN LUTFD2/TFRT--5473--SE, May 1993.

Nilsson, Ingemar, and Fredrik Rosberg: "Implementering av en generell fuzzyregulator i G2," (Implementation of a general fuzzy controller in G2). Master thesis ISRN LUTFD2/TFRT--5462--SE, October 1992.

Nilsson, Mikael: "Numerisk lösning av det inverskinematiska problemet," (Numeric solution of the inverse kinematic problem). Master thesis ISRN LUTFD2/TFRT--5474--SE, June 1993.

Olsson, Torbjörn, and Jörgen Svensson: "Snabb självinställande regulator," (A fast adaptive controller). Master thesis ISRN LUTFD2/TFRT--5461--SE, August 1992.

Persson, Håkan: "A comparison between conventional controllers and fuzzy controllers." Master thesis ISRN LUTFD2/TFRT--5468--SE, January 1993.

Strandh, Magnus, and Anders Ströbeck: "Object-oriented structuring of heating, ventilation, and air-conditioning systems." Master thesis ISRN LUTFD2/TFRT--5470--SE, February 1993.

Tunestål, Per: "Scanned image processor for X11 motif." Master thesis ISRN LUTFD2/TFRT--5467--SE, February 1993.

Internal Reports

Andersson, Mats: "OmSim and Omola tutorial and user's manual." Report ISRN LUTFD2/TFRT--7504--SE, April 1993.

Hang, C. C., and Karl Johan Åström: "PI/PID control of resonant dynamics." Report ISRN LUTFD2/TFRT--7501--SE, December 1992.

Hansson, Anders: "Non-linear stochastic control of critical processes." Report ISRN LUTFD2/TFRT--7503--SE, March 1993.

Johansson, Karl Henrik: "Difficulties when applying SISO relay design methods to a MIMO system." Report ISRN LUTFD2/TFRT--7506--SE, May 1993.

Johansson, Rolf, Ulf Jönsson, and Henrik Olsson, Eds.: "Processidentifiering – Projektarbeten hösten 1992," (Term papers in process identification – fall 1992). Report ISRN LUTFD2/TFRT--7499--SE, January 1993.

Jönsson, Ulf, and Henrik Olsson: "Nonlinear analysis of a simple adaptive system." Report ISRN LUTFD2/TFRT--7495--SE, October 1992.

Jönsson, Ulf, and Henrik Olsson: "Stability theory using Lipschitz and Dahlquist functionals." Report ISRN LUTFD2/TFRT--7502--SE, April 1993.

Larsson, Jan Eric: "An MFM toolbox." Report ISRN LUTFD2/TFRT--7493--SE, December 1992.

Larsson, Jan Eric: "Adaptation and learning. A comparison of AI and control views." Report ISRN LUTFD2/TFRT--7505--SE, April 1993.

Lord, Magnus: "Simulering av ett enkelt neurosystem," (Simulation of a simple neuronet). Report ISRN LUTFD2/TFRT--7496--SE, November 1992.

Nilsson, Bernt: "A chemical plant model in Omola." Report ISRN LUTFD2/TFRT--7507--SE, June 1993.

Olsson, Henrik, and Karl Johan Åström: "Friction modelling." Report ISRN LUTFD2/TFRT--7500--SE, January 1993.

Persson, Per: "The dominant pole design toolbox." Report ISRN LUTFD2/TFRT--7497--SE, December 1992.

Persson, Per: "The dominant pole design toolbox—the Matlab code." Report ISRN LUTFD2/TFRT--7498--SE, December 1992.

Reports Available

Some abstracts and reports are available by anonymous FTP from

`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

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F. Seminars at the Department

Seminars given at the department during the academic year 1992–1993, are summarized here. They are given both by the staff at the department and by invited lecturers.

1992

Aug 14	Torbjörn Olsson and Jörgen Svensson: "A fast adaptive controller." MSc-thesis presentation.
Aug 24	Michel Gevers (Louvain, Belgium): "Estimation of transfer function error bounds."
Aug 24	Michel Gevers (Louvain, Belgium): "Interconnections between identification and control."
Aug 25	Michel Gevers (Louvain, Belgium): "An iterative identification and control design scheme."
Aug 25	Bo Bernhardsson: "Robust performance optimization using models from standard identification."
Aug 26	Gustaf Söderlind (DNA): "Nonlinear stability, Lipschitz-algebra and 'small-gain theorems'."
Sep 4	Karl Johan Åström: "How adaptive are adaptive controllers."
Sep 8	Antoni Guasch (Barcelona, Spain): "Hierarchical continuous simulation."
Sep 10	V. A. Yakubovich (Russia): "Linear-quadratic optimization problems with quadratic constraints."
Sep 11	Anders Hansson: "Fuzzy anti-reset windup."
Sep 15	Björn Wittenmark: "Computational aspects of adaptive control."

Sep 18 Tore Hägglund: "Disturbance supervision in feedback loops."

Sep 24 D. P. Atherton (Brighton, UK): "Non-linear PID control."

Sep 25 Video seminar "1992 Robotics and automation, Conference Video Proceedings."

Sep 29 H. Verbrüggen and A. Krijgsman (TU, Delft): "Presentation about the knowledge-based control activities at TU Delft."

Sep 30 Per-Olof Gutman (Technion, Haifa): "Self-oscillating adaptive design of systems with dry friction and significant parameter uncertainty."

Oct 16 Ingemar Nilsson and Fredrik Rosberg: "Implementering av en generell Fuzzy-regulator i G2." MSc-thesis presentation.

Oct 21 Silvano Belami (ETH, Zürich): "Control of discrete event systems at a logical level."

Oct 22 Silvano Belami (ETH, Zürich): "Control of a rapid thermal multiprocessor."

Oct 23 Gunnar Johannsen (Univ of Kassel): "Relationship between integrated automation and advanced man-machine interfaces."

Oct 27 Bo Bernhardsson: "Topics in digital and robust control of linear systems." Doctoral dissertation defence. Opponent: David Limebeer (London).

Oct 27 David Limebeer (London): "Topics in H_∞ control."

Oct 27 Pierre Bernhard (INRIA, Sophia Antipolis): "H_∞ optimal control for infinite dimensional systems."

Nov 11 Carlos Canudas (Grenoble): "Examples of piecewise stabilization of driftless nonlinear systems with less inputs than states."

Nov 20 C. C. Hang (Singapore): "Tuning of PI/PID controllers based on gain and phase margin specifications."

Nov 20 Albert-Jan Baerveldt (ETH, Zürich): "The fastest ping-pong robot in the world." A video included.

Nov 23 C. C. Hang (Singapore): "Extension of relay feedback auto-tuning of PI/PID controllers for multi-loop and multivariable systems."

Nov 27 Gunnar Bengtsson (First Control, Lund): "Adaptive control – How did it work in practice?."

Dec 2 Brett Ninness (Univ of Newcastle, Australia): "A stochastic approach to robust estimation."

Dec 9 Anders Sjö (DNA, LTH): "Updating techniques in recursive least squares estimation."

Dec 10 Thomas Idoffsson and Mats Wennberg: "Speed control of an internal-combustion engine." MSc-thesis presentation.

Dec 11 Jan Eric Larsson: "Knowledge-based methods for control systems." Doctoral dissertation defence. Opponent: Henk Verbrüggen (Holland).

Dec 14 Sören Andersson (KTH, Stockholm): "Friction models."

Dec 14 Ilan Cohen (Servotech, Israel): "Improving the performance of electromechanical control systems."

Dec 14 Ilan Cohen (Servotech, Israel): "Automatic design of controllers to servo systems."

Dec 16 C. C. Hang (Singapore): "Improvement of transient response by means of variable setpoint weighting."

Dec 21 Per Persson: "Neural networks and fuzzy systems." Going through the book by Bart Kosko.

Dec 21 Karl Johan Åström: "Research evaluation."

1993

Jan 25	Björn Wittenmark and Rolf Johansson: "Report from the CDC conference."
Jan 25	Björn Wittenmark: "Adaptive control of a stochastic non-linear system."
Feb 4	Per-Olof Källén: "Frequency domain estimation."
Feb 5	Rainer Scheuring (Stuttgart): "Design of DES by means of the Boolean differential calculus."
Feb 8	Tim Berg (Univ of Oxford): "The decentralized and distributed information filter."
Feb 11	Per Tunestål: "Scanned image processor for X11/Motif." MSc-thesis presentation.
Feb 11	Chun-Ming Lu: "Flight planning system for X11/Motif." MSc-thesis presentation.
Feb 23	Jorge Angeles (McGill University): "The role of rotational representations in computational robot kinematics."
March 1	Håkan Persson: "A comparison between fuzzy controllers and conventional controllers." MSc-thesis presentation.
March 1	Magnus Strandh and Anders Ströbeck: "Object-oriented structuring of HVAC processes." MSc-thesis presentation.
March 22	Rolf Johansson: "Multivariable system identification."
April 2	Sven Erik Mattsson: "Simulation – An engineering tool of increasing importance." Docent lecture.
April 27	Ulf Holmberg: "Robust stochastic model control."
April 27	Ulf Holmberg: "Impressions from Japan."
April 27	Mats Andersson, Dag Brück and Sven Erik Mattsson: "How to run OmSim."
May 4	Lars Malcolm Pedersen: "The plate mill at The Danish Steelworks, Ltd."

May 7	Karl Johan Åström: "Control structures and control design."
May 14	Karl-Erik Årzén: "Object-oriented sequence nets for control and supervision of industrial processes."
May 18	Ola Dahl: "Impressions from IEEE International Conference on Robotics and Automation." A video included.
May 25	Henrik Olsson: "A new model for control of systems with friction."
May 28	Frode Maaseidvaag (Ford Motor Company): "Research at Ford Research Laboratories." A video included.
June 1	Anders Hansson: "Non-linear stochastic control of critical processes."
June 2	Anders Carlsson: "A small, fast real-time kernel in C implementation for DSP with an example." MSc-thesis presentation.
June 4	Ola Dahl: "Reference trajectory generation for single-loop controllers."
June 14	Mikael Nilsson: "Numeric solution of the inverse kinematic problem." MSc-thesis presentation.
June 14	Lars Engelin: "Object-oriented implementation for signal processors of motor control and sensor readings." MSc-thesis presentation.
June 16	Paul A. Fishwick (Univ of Florida): "Multimodeling as a unified approach to modeling large scale dynamical systems."

G. Lectures by the Staff

1992

July 1	Karl Johan Åström: "Automatic tuning and adaptation for PID controller—A survey," Invited paper, 4th IFAC Int. Symposium on Adaptive Systems in Control and Signal Processing, Grenoble, France.
July 1	Per Persson: "Dominant pole design—A unified view of PID controller tuning," 4th IFAC Int. Symposium on Adaptive Systems in Control and Signal Processing, Grenoble, France.
July 2	Karl Johan Åström: "Automatic initialization of robust adaptive controllers," 4th IFAC Int. Symposium on Adaptive Systems in Control and Signal Processing, Grenoble, France.
July 2	Karl Johan Åström: "Automatic tuning of a digital controller," 4th IFAC Int. Symposium on Adaptive Systems in Control and Signal Processing, Grenoble, France.
July 2	Karl Johan Åström: "Intelligent tuning," Invited Plenary Talk, 4th IFAC Int. Symposium on Adaptive Systems in Control and Signal Processing, Grenoble, France.
July 2	Rolf Johansson: "Supermartingale analysis of minimum variance adaptive control," IFAC Int. Symp. Adaptive Systems in Control and Signal Processing, Grenoble, France.
July 17	Anders Hansson: "Stochastic control of critical processes," Institut d'Automatique, Ecole Polytechnique Fédérale de Lausanne, DME-Ecublens, Lausanne, Switzerland.
July 22	Anders Hansson: "Stochastic control of critical processes," Fachgruppe Für Automatik, ETH-Zentrum, Zürich, Switzerland
July 28	Anders Hansson: "Stochastic control of critical processes,"

Laboratoire d'Automatique de Grenoble, ENSIEG, Saint-Martin-d'Hères Cedex, France.

Aug 18 Mats Andersson: "Omola and OmSim," Joint seminar on model development, LTH and LiTH, Linköping, Sweden.

Aug 18 Karl-Erik Årzén: "Model-based diagnosis," Joint seminar on model development, LTH and LiTH, Linköping, Sweden.

Aug 18 Karl-Erik Årzén: "Grafcet and Petri nets in G2," Joint seminar on model development, LTH and LiTH, Linköping, Sweden.

Aug 18 Jan Erik Larsson: "Multi flowlevel modelling," Joint seminar on model development, LTH and LiTH, Linköping, Sweden.

Aug 18 Jan Eric Larsson: "Diagnostic reasoning strategies for means-end models," Divison of Automatic Control, Linköping University

Aug 18 Sven Erik Mattsson: "Index reduction and manipulation of DAE-systems," Joint seminar on model development, LTH and LiTH, Linköping, Sweden.

Aug 18 Bernt Nilsson:"Modelling of Chemical Processes in Omola," Joint seminar on model development, LTH and LiTH, Linköping, Sweden.

Aug 19 Ola Dahl: "Path constrained robot control," ETH, Zürich, Switzerland.

Aug 20 Anders Hansson: "Fuzzy Anti-Reset Windup," Zentrallabor, Landis & Gyr Betriebs A.G., Zug, Switzerland.

Aug 21 Ola Dahl: "Path constrained robot control," EPFL, Lausanne, Switzerland.

Sep 1 Björn Wittenmark: "Computational aspects of adaptive control," Plenary talk, IFAC Workshop on Mutual Impact of Computing Power and Control Theory, Prague, Czechoslovakia.

Sep 8 Tore Hägglund: "Industrial adaptive control based on frequency response techniques," Swedish-Russian Control

Conference, Linköping, Sweden.

Sep 3 Björn Wittenmark: "Adaptive control," Summer school on Modern Control Theory at Czechoslovakian Technical University, Prague.

Sep 8 Per Hagander: "Properties of H_∞-optimal control investigated using a simple test example," Swedish-Russian Control Conference, Linköping, Sweden.

Sep 10 Sven Erik Mattsson: "Object-oriented modelling and simulation," The course "Advanced Control for the Process Industries", Cambridge Programme for Industry, Department of Engineering, University of Cambridge, UK.

Oct 7 Karl-Erik Årzén: "Intelligent process control," INTERKAMA Congress, Dusseldorf, Germany.

Oct 8 Tore Hägglund: "Adaptive techniques in the SattControl ECA400 controller," Conference on Control of Difficult Processes, Copenhagen, Denmark.

Oct 12–14 Karl Johan Åström: "Minicourse on Adaptive Control," Department of Control and Instrumentation Engineering, Seoul National University, Seoul, Korea.

Oct 14 Karl Johan Åström: "Intelligent control," Department of Control and Instrumentation Engineering, Seoul National University, Seoul, Korea.

Oct 14 Karl Johan Åström: "The development of distributed control systems," Department of Control and Instrumentation Engineering, Seoul National University, Seoul, Korea.

Oct 15 Karl Johan Åström: "Tuning and adaptation of simple controllers," Goldstar, Seoul, Korea.

Oct 16 Karl Johan Åström: "Intelligent tuning for process control systems," Pohang Institute of Science and Technology (POSTECH), Pohang, Korea.

Oct 16 Anders Rantzer: "Robustness analysis in presence of uncertainties bounded by quadratic forms," Control Science/Dynamical Systems Seminar Series, University of Minnesota.

Oct 17 Karl Johan Åström: "Use of relay feedback in intelligent control," International Workshop on Robust and Intelligent Control, Engineering Research Center for Advanced Control and Instrumentation at Seoul National University, Seoul, Korea.

Oct 18 Karl Johan Åström: "Intelligent control," Invited keynote lecture, Korean Automatic Control Conference, Seoul, Korea.

Oct 20 Mats Andersson: "A new modeling and simulation language for hybrid systems," Workshop on Theory of Hybrid Systems, Lyngby, Denmark.

Oct 20 Karl Johan Åström: "Automatic tuning of PID controllers," Yonsei University, Seoul, Korea.

Oct 28 Anders Rantzer: "Real parametric uncertainty in linear systems," Institute for Mathematics and its Applications, University of Minnesota.

Oct 29 Ola Dahl: "Interactive programming of robot motions," NUTEK, Stockholm.

Nov 3 Karl-Erik Årzén: "Knowledge-based real-time control systems," Technical University of Darmstadt, Germany.

Nov 4 Karl Johan Åström: "Relay oscillations," Reglermöte '92, Chalmers Technical University, Gothenburg, Sweden.

Nov 4 Sven Erik Mattsson: "Omola—An object-oriented modelling language," Reglermöte '92, Chalmers Technical University, Gothenburg, Sweden.

Nov 5 Karl-Erik Årzén: "Grafcet, coloured Grafcet, and CPN in G2," Reglermöte '92, Chalmers Technical University, Gothenburg, Sweden.

Nov 6 Karl Johan Åström: "Inertial navigation," Engineering Physics, Lund Institute of Technology, Lund, Sweden.

Nov 7 Karl Johan Åström: "Mathematical models for human brain functions," Seminars on brain research, Lund University Library.

Nov 11 Tore Hägglund: "Automatic supervision of control loop performance," Reglermöte '92, Linköping, Sweden.

Nov 18 Karl Johan Åström: "Relay oscillations," Royal Institute of Technology, Stockholm, Sweden.

Nov 23 Karl-Erik Årzén: "Knowledge-based real-time control systems," Delft Technical University, The Netherlands.

Nov 24 Jan Eric Larsson: "Diagnostic reasoning strategies for means-end models," Department of Automatic Control, Faculty of Electrical Engineering, Delft Technical University, The Netherlands.

Dec 7 Karl Johan Åström: "From calculus of variations to optimal control," Department of Mathematics, Lund Institute of Technology.

Dec 9 Björn Wittenmark: "Adaptive control of a stochastic nonlinear system: An example," 2nd Workshop on Adaptive Control: Applications to Nonlinear Control and Robotics, Cancun, Mexico.

Dec 15 Sven Erik Mattsson: "Omola—An object-oriented modelling language," Colloquium on Open systems: the way forward in computer aided control engineering, The Institution of Electrical Engineers, London, UK.

Dec 16 Rolf Johansson: "Identification of continuous-time models," 31st IEEE Conference on Decision and Control, Tucson, Arizona.

1993

Jan 6–13 Anders Rantzer: "Robustness of Linear Control Systems," Five seminars, Dept. of Electrical Engineering, Caltech, Pasadena, California.

Jan 15 Jan Eric Larsson: "Diagnostic reasoning with MFM," Workshop on Modeling Problems in Control and Supervision of Complex Dynamic Systems, Technical University of Denmark, Lyngby, Denmark.

Jan 15 Anders Rantzer: "Parametric uncertainty with bounded rate of variation," Dept. of Electrical Engineering, UC Santa Barbara, California.

Jan 19 Bo Bernhardsson: "Min-mix control using classical stochastic differential game theory," IMA, University of Minnesota.

Jan 20 Karl Johan Åström: "Automatic control at Lund Institute of Technology," Control and Dynamical Systems, Caltech, California.

Feb 3 Karl Johan Åström: "Object oriented modeling and simulation of control processes," Control and Dynamical Systems, Caltech, California.

Feb 10 Sven Erik Mattsson: "Object-oriented modelling and simulation," Meeting on Collaboration Project for Simulation of Electrical Components, Ericsson Components, Kista, Sweden.

March 3 Karl Johan Åström: "Relay feedback," Control and Dynamical Systems, Caltech, California.

March 9 Tore Hägglund: "Automatic supervision of control loop performance," University of Aveiro, Portugal.

March 10 Tore Hägglund: "Automatic supervision of control loop performance," Instituto Superior Técnico, Lisbon, Portugal.

March 17 Henrik Olsson: "A new model for control of systems with friction," NASA Jet Propulsion Laboratory, Pasadena, California.

March 19 Henrik Olsson: "A new model for control of systems with friction," University of California at Santa Barbara, California.

March 23 Karl Johan Åström: "Computer science and automatic control," Symposium on Current Developments in the Computer Sciences, UCLA, Los Angeles, California.

March 23 Björn Wittenmark: "Practical issues and case studies in adaptive control," IEEE Joint Chapter, Denmark Technical University, Lyngby, Denmark.

March 26 Björn Wittenmark: "Adaptive control of a stochastic nonlinear system: An example," Department of Optimization and Systems Theory, Royal Institute of Technology, Stockholm, Sweden.

March 29 Karl Johan Åström: "Unifying criteria for control and identification," Control and Dynamical Systems, Caltech, California.

March 30 Bo Bernhardsson: "Sampling of state space systems with several time delays," IMA, University of Minnesota, USA

March 31 Karl Johan Åström: "Experiences in technology transfer at the Lund Institute of Technology, Sweden." Nasa Jet Propulsion Laboratory, Pasadena, California.

April 5 Tore Hägglund: "Disturbance supervision in feedback loops," International Conference on fault diagnosis, Tooldiag'93, Toulouse, France.

April 8 Karl Johan Åström: "Implementation issues and applications," Lectures at the Tutorial on Adaptive Systems, Institute for Mathematics and its Applications, University of Minnesota, Minneapolis.

April 9 Bo Bernhardsson: "A use of duality in control and signal processing," Mechanical Engineering, University of Minnesota.

April 12 Karl Johan Åström: "Unifying criteria for control and identification," Workshop on Adaptive Control, Filtering and Signal Processing, IMA, University of Minnesota, Minneapolis.

Apr 14 Anders Rantzer: "Parametric uncertainty with bounded rate of variation," Workshop on Adaptive Control, Filtering and Signal Processing, IMA, University of Minnesota, Minneapolis.

April 29 Jan Eric Larsson: "Can Searle think?," School of Electrical Engineering and Computer Science, Lund Institute of Technology, Lund.

May 5 Karl Johan Åström: "Integrated control and diagnosis," Symposium on research in the pulp and paper industry, Lund Institute of Technology, Lund, Sweden.

May 5 Ola Dahl: "Path constrained motion optimization for rigid and flexible joint robots," IEEE International Conference on Robotics and Automation, Atlanta, Georgia.

May 6 Ola Dahl: "Path constrained robot control with limited torques – Experimental Evaluation," IEEE International Conference on Robotics and Automation, Atlanta, Georgia.

May 14 Jan Eric Larsson: "Diagnosis with explicit models of goals and function," ITM/NUTEK Seminar on Complex Systems, KTH/EKC, Stockholm.

May 26 Karl Johan Åström: "Adaptive control – Past, present and future," Invited paper, LAAS-CNRS 25th Anniversary, Toulouse, France.

June 1 Bo Bernhardsson: "How to compute the real stability radius," Stanford University, California.

June 1 Anders Rantzer: "A convex parameterization of robustly stabilizing controllers," ISL, Stanford University, California.

June 2 Bo Bernhardsson: "Min-mix control using classical stochastic differential game theory," American Control Conference, San Fransisco, California.

June 2 Anders Rantzer: "Uncertainties with bounded rate of variation," American Control Conference, San Francisco, California.

June 3 Henrik Olsson: "Dynamic friction models and control design," American Control Conference, San Francisco, California.

June 9 Sven Erik Mattsson: "Towards a new standard for modelling and simulation tools," SIMS'93, 35th Simulation Conference Applied Simulation in Industry Kongsberg, Norway.

June 18 Sven Erik Mattsson: "Object-oriented simulation tools," The course "Stability and Control of Power Networks," Electric Energy Systems University Enterprise Training Partnership, EES-UETP, at the Department of Electric Power Systems, Royal Institute of Technology, Stockholm, Sweden.

June 28 Karl Johan Åström: "Matching criteria for control and identification," European Control Conference, ECC'93, Groningen, The Netherlands.

June 30 Karl Johan Åström: "History of adaptive control," European Control Conference, ECC'93, Groningen, The Netherlands.

July 1 Per Hagander: "Min-mix control in discrete time by completion of squares," European Control Conference, ECC'93, Groningen, The Netherlands.

H. Travels

On May 10, 1993, the members of the department made a visit at the plate mill at The Danish Steelworks, Ltd, in Frederiksværk, Denmark.

Mats Andersson attended the Workshop on Theory of Hybrid Systems, held in October 1992 in Lyngby, Denmark, where he gave a presentation.

Karl-Erik Årzén visited the INTERKAMA fair in Düsseldorf, in October. Also in October he participated in the Workshop on Theory of Hybrid Systems, at the Technical University of Denmark. In November he visited Professor Rolf Isermann at the Technical University of Darmstadt for a couple of days. He participated in Reglermöte '92 held in Gothenburg in November. Also in November he made a two days visit to Professor Henk Verbruggen at the Delft Technical University, The Netherlands. In March 1993 he participated in a meeting of the Esprit III working group FALCON on fuzzy control in Albi, France.

Karl Johan Åström participated in the 4th IFAC Int. Symposium on Adaptive Systems in Control and Signal Processing in Grenoble, France, in July 1992. In October he was invited to Korea to deliver a plenary lecture on Intelligent Control at the Korean Automatic Control Conference. In connection with this he also gave a short course and several lectures. From January through March 1993 Åström was Distinguished Fairchild Scholar at Caltech. In April he participated in the workshop on Adaptive Control at the Institute of Mathematics and Its Application at University of Minnesota. He was also a coorganizer of the workshop. In May 1993 he was invited to give a plenary lecture at a symposium celebrating the 25th anniversary of LAAS in Toulouse. In June he participated in the 2nd European Control Conference in Groningen.

Bo Bernhardsson worked as a post-doc at the Institute for Mathematics and its Applications (IMA) at the University of Minnesota from November 1992 until June 1993. The stay was partly financed by the Sweden-America foundation and by IMA. There he participated in about ten different workshops, tutorials and conferences during the special year for control theory and applications. He also visited Stanford University and the American Control Conference, San Francisco, in June 1993.

Ola Dahl visited ETH in Zürich and EPFL in Lausanne in August 1992. In October he participated in a NUTEK meeting in Stockholm and in November he visited ABB Robotics in Västerås. In May 1993, he participated in the IEEE International Conference on Robotics and Automation, Atlanta, Georgia.

Kjell Gustafsson spent the academic year 92/93 as a post-doc at Stanford University, working on sensor array problems. The stay was partly financed with scholarships from the Hans Werthén fund and the Claes Adelskölds. During the year at Stanford, Kjell Gustafsson participated in several conferences: the 31st IEEE conference on Decision and Control (CDC) in Tuscon, Arizona; Object Oriented Numerics Conference (OON-SKI'93) in Sunriver, Oregon; 1993 American Control Conference (ACC) in San Francisco, California; and the 12th Householder Symposium on Numerical Algebra at Lake Arrowhead, California.

Per Hagander participated in ECC'93, the European Control Conference, in June/July 1993, and in the Swedish-Russian Control Conference held in Linköping in September 1992. He presented a paper at both meetings.

Tore Hägglund visited Linköping in September to give lectures at the Swedish-Russian Control Meeting. In October he visited Copenhagen and gave a lecture at the conference on Control of Difficult Processes. In November he participated in Reglermöte '92, held in Gothenburg, and gave a lecture. In March 1993 he visited Aveiro and Lisbon in Portugal, where he gave lectures and acted as an external examiner

for the dissertation of Alexandre Manuel Mota. In April he presented a paper at the conference International Conference on fault diagnosis, Tooldiag'93, in Toulouse, France. Tore Hägglund has also lectured on industrial courses at The Training Centre of the Forest Industries in Markaryd, Sweden, and at SattControl AB in Stockholm, Sweden.

Anders Hansson visited in July 1992 the departments of automatic control in Lausanne, Zürich, and Grenoble, where he presented some of his research. From October until April he visited Professor Mark H. A. Davis at the Department of Electrical Engineering, Imperial College of Science, Technology and Medicine, London.

Karl Henrik Johansson participated in Young Scientists' Summer Program at the International Institute of Applied System Analysis in Vienna from 1 June to 31 August 1993. There he worked with economic modeling in the Dynamic Systems project.

Rolf Johansson participated in IFAC Int. Symposium on Adaptive Systems in Control and Signal Processing, Grenoble, France, in July 1992. He participated in the 31st IEEE Conference on Decision and Control in Tucson, Arizona, in December 1992. In June 1993 he participated in Robotikdagar in Linköping, Sweden, and in the XXth Neurootological and Equilibriometric Society Congress, also in Linköping.

Jan Eric Larsson participated in November in a visit to the Department of Automatic Control at the Technical University of Delft, with the aim of creating more unofficial contacts between the researchers at this department and Lund. He presented his doctor's project. In January 1993 he participated in the Workshop on Modeling Problems in Control and Supervision of Complex Dynamic Systems at the Institute of Automatic Control Systems, Technical University of Denmark, Lyngby, Denmark. A paper was presented.

Sven Erik Mattsson was in September in Cambridge to give lectures in an industry course and to discuss with Jan Maciejowski and his colleagues. He participated in Reglermöte '92, Gothenburg, and presented

and demonstrated Omola and OmSim. In December he was in London to participate in the IEEE Colloquium on Open systems: the way forward in computer aided control engineering. He also visited Professor C. C. Pantelides at Imperial College. In June 1993 he participated in SIMS'93, Kongsberg, Norway.

Henrik Olsson visited California Institute of Technology, Pasadena, University of California at Santa Barbara, and University of Maryland at College Park in March 1993. In June he attended the American Control Conference in San Francisco, where he presented a paper, and visited University of California at Santa Barbara.

Per Persson is visiting the Electrical Engineering Department at Automation Technology Laboratory in Singapore from January 1993.

Anders Rantzer has spent the academic year 1992/93 as a post-doc at Institute for Mathematics and its Applications (IMA), University of Minnesota. This year, the program title at IMA has been "Control Theory and its Applications" and many workshops, minisymposia etc. have been arranged. The opportunities for interaction with other researchers have been splendid. Furthermore, Rantzer has paid shorter visits at other conferences and universities, in particular CDC in Tucson in December, Caltech, and UC Santa Barbara two weeks in January 1993 and, finally, Stanford and American Control Conference in San Francisco in June.

Björn Wittenmark participated in the 2nd Workshop on Adaptive Control: Applications to Nonlinear Control and Robotics, Cancun, Mexico; and in the Conference on Decision and Control, Tucson, Arizona, both conferences held in December 1992.