Activity Report: Automatic Control 1990-1991

Dagnegård, Eva; Åström, Karl Johan

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Department of Automatic Control
Lund Institute of Technology
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S-221 00 Lund Sweden

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Eva Dagnegård and Karl Johan Åström

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Abstract

The report surveys the activities during the academic year 1990/91 (1 July 1990 – 30 June 1991) at the Department of Automatic Control, Lund Institute of Technology, Lund, Sweden.

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Department of

Automatic Control

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Mailing address:

Department of Automatic Control
Lund Institute of Technology
P.O. Box 118
S–221 00 Lund SWEDEN

Visiting address:

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

Telephone:

Nat 046–10 87 80
Int +46 46 10 87 80

Fax:

Nat 046–13 81 18
Int +46 46 13 81 18

Telex:

S–33533 LUNIVER

The report is edited by
Eva Dagnegård and Karl Johan Åström

Contents

1. Introduction

This report covers the activities at the Department of Automatic Control at Lund Institute of Technology (LTH) during the period 1 July 1990 – 30 June 1991, which is the academic year 1990/91. The budget for the year was 13.2 MSEK. This figure does not include rent for offices and laboratories.

During this period Bo Eliasson and Lars Rundqwist completed their PhD theses. This brings the total number of PhDs graduating from our department to 33. Twenty-one students completed their MSc degree at the department. One book was published, Hägglund (1991). Seventeen journal papers and 48 conference papers were published by staff members.

About 500 students graduated from seven courses in the civ.ing. program. There was a very high activity in the control laboratory with 800 groups × experiments. Four 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.

Researchers at the department received distinguished international awards during the year. Professor Åström received an IEEE Field Award, Professor Wittenmark was elected an IEEE Fellow and Kjell Gustafsson and Lars Rundqwist were runners up for the Young Author Prize at the 11th IFAC World Congress.

The computing facilities have been upgraded significantly thanks to generous contributions from the Knut and Alice Wallenberg Foundation and the Swedish Council for Planning and Coordination of Research.

The report is organized as follows. Economics and facilities are presented in Section 2. The educational activity is described in Section 3. Some project areas are highlighted in Section 4, and the dissertations completed during the year are presented in Section 5. Detailed informations about awards, publications, seminars and lectures are given in the Appendices.

Acknowledgement

We want to thank our sponsors, the Swedish Board for Technical Development (STU), the Swedish Council for Planning and Coordination of Research (FRN), the National Energy Administration (Statens energiverk), the Swedish Medical Research Council (MFR), Sydkraft, Vattenfall, the Knut and Alice Wallenberg Foundation, and Apple Computer for their support to our projects.

2. Economics and Facilities

Economics

The income for the academic year 1990/91 was 13.2 MSEK. This does not include rent for offices and laboratories, which is free. We had a large grant of 1 MSEK for upgrading of our computer system. The remaining income is distributed as follows: 65% from the university, 21% from government agencies, 9% from industry, and 5% from software contracts and small projects.

The operating costs are: salaries 9.6 MSEK, university overhead 0.4 MSEK, and operating costs 3.2 MSEK. The operating costs cover the costs for running computers and laboratories, publishing, travel etc.

The average number of members were 33. The department had eight scientific visitors during the year. Details of the personnel are given in Appendix A.

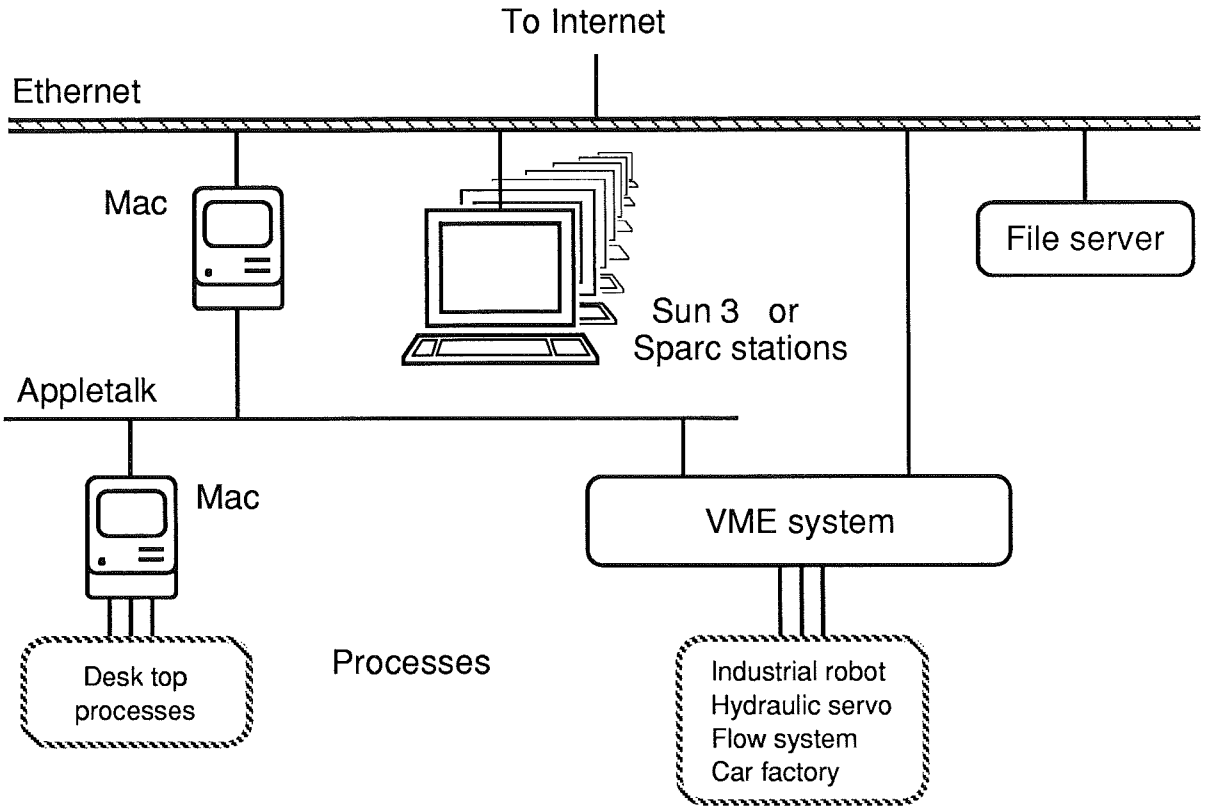
Computer Facilities

A major upgrade of the computing facilities was made thanks to support from FRN and Alice and Knut Wallenberg Foundation. All staff members now have good access to workstations. The system has been a major factor in increasing the productivity at the department. Donations from Apple Computer, Texas Instruments, and National Instruments (Austin, Texas) have provided the beginning of a new creativity laboratory. A cheap Appletalk connection to VME systems has been developed.

Among the more interesting software that has been installed we can mention Xmath from Integrated Systems Inc, new C++ cross

compilers with Motorola 680x0 and the DSP-32 signal processor from AT&T as target machines.

A schematic of our present computer configuration is shown in the figure below.



The total computer capabilities of the department are as follows:

- A **Sun Workstation** network served by a Sun 4/390 with 2.6 GB disk. There are 18 SPARCstations and 12 older workstations of type Sun3. Four of the workstations have color monitors.

- Four **Macintosh II**, for text processing and for creating figures and drawings for the technical reports. A special program enables the inclusion of drawings produced on the Macintosh directly into TEX documents produced on the Suns. All Macintoshes have Ethernet and are connected to each other and to the Sun network.

- A **Macintosh Creativity Lab** with two Macintosh II intended for development of control engineering software in a Macintosh environment. Apart from general software there is also LabView from National Instruments, containing hardware and software for data acquisition and control.

- A **VME based Laboratory System** with Motorola 68030 CPU and AT&T DSP-32 signal processors and analog I/O. See the subsection "Robotics and Sensory Control" in Section 3.

- An **Undergraduate Computer Lab** with 5 Sun 3/80 workstations and lab computers with 68020:s. The programming is done in Modula-2, which is cross-compiled and linked on the Suns using a compiler from Oregon Software. The basic real-time software for the lab computers is in a reasonably mature state, and has been used successfully in undergraduate projects. The acheivable sampling rate is up to 1 kHz.

  The workstations are also used in undergraduate courses for Matlab, Simnon and other program packages. They are freely available to the students any time of day.

- Fourteen **IBM-AT** or compatibles with 640 kB memory and 20 MB disk. They have analog input and output channels (4 or 16 channels in and 2 or 8 channels out) and also some digital I/O. The main use of these computers is for real time control, both in formal lab exercises and projects in the undergraduate courses, and also in research projects by graduate students and faculty. The programming is done almost exclusively in Modula-2, and a library containing a real time kernel and real time graphics has been developed. The achievable sampling rates is up to 100 Hz.

  These machines are primarily used in the undergraduate program. They will have to be replaced in the future.

3. Education

Engineering Program

The engineering education follows the central European system with a 4.5 year program leading up to the degree civ ing (civilingenjör), which is equivalent to an MSc in the Brittish and US system.

Automatic control courses are taught as a part of the engineering curricula in Engineering Physics (F), Electrical Engineering (E), Computer Engineering (D), Mechanical Engineering (M), and Chemical Engineering (K).

During the year the following courses were given at the department:

Name of the course (Section)	**Number of students**
Reglerteknik AK (F, E, D)	
(Automatic control, linear systems)	228
Reglerteknik AK (M)	
(Automatic control, linear systems)	69
Processreglering (K)	
(Automatic Process control)	84
Digital reglering (F, E, D)	
(Computer controlled systems)	80
Datorimplementering av reglersystem (F, E, D)	
(Computer implementation of control systems)	25
Processidentifiering (F, E, D)	
(System identification)	11
Adaptiv reglering (F, E, D)	
(Adaptive control)	22

The first four courses are comparable to undergraduate courses and the last two are equivalent to graduate courses in the US system. In

summary 519 students have passed courses in the department during the academic year 1990/91.

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. The total load of the lab has been 800 groups $\times$ experiments. In the basic courses we can have eight parallel groups and in the elective courses we have four parallel experiments. During the fall semester the lab is used for about 80% of the time. For sceduling reasons there are also many laboratory experiments in the evenings. The load is less in the spring semester.

Master Theses

Twenty-one students completed their master theses during the year. A list is given in Appendix D. This brings the total number of students, who have written their Master theses at our department, to 556.

The theses concerned the following application areas: Adaptive control (2), Biomedical engineering (2), Computer aided design and computer graphics (1), Controller implementation (1), Knowledge-based systems (4), Process control (2), Robotics and servo mechanisms (3), and System identification (6).

Doctorate Program

Two PhD theses were completed during the period, Eliasson (1991) and Rundqwist (1991). The abstracts of these are given in Chapter 5. This brings the total number of PhDs graduating from our department to 33. Two new PhD students (Ulf Jönsson, Henrik Olsson) were admitted to the department.

The following PhD courses have been given:

Neural Nets, 4+2 p	(K. J. Åström)	Fall 1990
Stochastic Control Theory, 4 p	(B. Wittenmark)	Sept–Nov 1990
H_∞-Optimal Control, 2 p	(T. Basar)	April 1991
Optimal Control, 4 p	(R. Johansson)	April–May 1991

The course on Optimal Control covered aspects of calculus of variations, dynamic programming, Hamilton-Jacobi theory, Pontryagin maximum principle, and numerical methods for optimal control.

Extension Courses

The extension program in automatic control offers courses for extended education of engineers in industry. The courses given by the department are:

Introduction to automatic control
Digital control
Simulation and modeling
Process identification
Adaptive control
Knowledge-based process control
Advanced C++

A course demands 3–4 days of attendance and takes 16–20 participants. Each course day usually consists of two or three lectures and a laboratory session of about four hours. The following course has been given during the period:

Advanced C++ 4–7 June 1991

The C++ course was given by Jonathan E. Shopiro of AT&T Unix Software Laboratories. Forty-one people attended the course.

4. Research

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

Adaptive control
Computer aided control engineering

We have application projects in

Knowledge-based control systems
Robotics and sensory control
Power systems

Minor projects have also been carried out in control of biotechnological processes and modeling and control of medical systems. Some projects are highlighted below.

Adaptive Control

The research in adaptive control covers a broad area:

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

Adaptive control research has been successful in the sense that several industrial products based on the ideas have emerged. There are, however, many issues still to be investigated. There is a widely spread international activity in benchmarking of algorithms. We are participating in this together with other leading research groups. There are two key challenges in making really useful adaptive systems. One is to combine robust and adaptive control, the other is to make adaptive systems easy to use.

Robust Adaptive Control

Researchers: Karl Johan Åström, Bo Bernhardsson, Per-Olof Källén, Mats Lilja, Michael Lundh, Björn Wittenmark

There are two ways to obtain control systems that are insensitive to parameter variations. One approach is robust control, the other is adaptive control. Robust control attempts to design a linear controller that can cope with the parameter variations. Adaptive control attempts to reduce the uncertainty about the system by using system identification. There are many approaches to robust control, LQG/LTR, μ, H_∞, $\mathcal{L}_1$ etc. The drawback with robust control is that it leads to conservative designs and that the design may require a significant effort. It is therefore appealing to combine the approaches. This is pursued in thesis projects by Lundh and Olsson.

Automatic Tuning

Researchers: Karl Johan Åström, Tore Hägglund, Ulf Holmberg, Per Persson

A drawback with many of the adaptive schemes is that they require *a priori* information. This means that significant engineering skills may be required to start adaptive controllers. Earlier we have developed methods for automatic initialization of PID controllers. The key idea is to exploit information from relay feedback. Since relay feedback is used extensively, it is important to understand when it can be used and what its limitations are. This has been investigated by a detailed analysis of low order systems with time delays. Work on improved tuning rules for PID controllers is also in progress. This has indicated that well-tuned PID controllers give surprisingly good behaviour.

A natural extension is to investigate if the methods for automatic tuning of PID controllers can be extended to adaptive controllers. If this is possible it could simplify the use of adaptive control significantly.

Expert Control

Researchers: Tore Hägglund, Karl Johan Åström, Per Persson, Karl Erik Årzén

Work on expert control has been going on since 1985. The goal of expert control is to extend the range of conventional controllers by encoding general control knowledge and heuristics concerning tuning and adaptation in a supervisory expert system. An important part of the project is architectures for real-time, on-line expert systems. The work during the last year has concentrated on PID design methods and an implementation of an expert controller based on the G2 expert system tool.

Heuristics for assessment of controller performance and the sizing of control loops have been investigated. It has also been attempted to include diagnosis in the feedback loop.

Computer Aided Control Engineering

The major effort in CACE is the development of an environment for modeling and simulation. There are also related projects on solvers for differential algebraic systems and for automatic step length adjustment in ODE.

A Modeling Environment

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

The CACE project has for a long time focused on model development and simulation. Mathematical models are important in all kinds of engineering and particularly in CACE), but model development is often a time consuming and difficult task. Today's most used languages for continuous simulation follow the CSSL definition from 1967. In 1967 it was necessary to adapt the simulation language to the computer, but since then there has been an enormous development

of information technology. We think it is now time to capitalize on this development and reconsider the foundations of model representation. Model development is facilitated by tools providing a set of high-level concepts for describing models of dynamic systems. If we could agree upon a common set of ideas we may lay the foundation to a new standard.

We have developed a new universal modeling language, based on ideas from object-oriented programming, called Omola. The language provides concepts for defining models in a structured and modular way. It also allows models and model components to be defined as specializations of previously defined models by using the inheritance concept adopted from object-oriented programming. Inheritance will facilitate model reuse. The model developer may supply extra information which is used for automatic consistency analysis to check for unintended abuse of models. A basic idea is that behaviour descriptions should be declarative and equation based so a model can be used for various purposes in different applications. The Omola language permits a wide variety of formalisms to describe behaviour.

A kernel to support modeling and simulation of continuous time models (differential-algebraic equations and difference equations) with discrete event elements is under implementation in C++. A version for internal use has been released.

An application project to model a gas-fired power system with a heat recovery steam generator in Omola has started. The project is supported by Sydkraft AB (The South Swedish Power Company Ltd).

Future research will be directed towards object-oriented modeling methodology and tool integration, i.e. how a set of tools should cooperate in an integrated environment in order to aid the user solving advanced problems in control and process design. The kernel will serve as a work-bench and a framework for further experiments in advanced user interfaces, symbolic model manipulation, design tool integration, etc.

DAE Solvers

Researchers: Sven Erik Mattsson in cooperation with Gustaf Söderlind (Dept of Numerical Analysis)

The natural mathematical notation when developing models of physical systems is often that of differential-algebraic equation (DAE) systems. It is well-known that many mathematical models of interest have high index, and that there is no reliable general-purpose software for solving high-index problems. To remedy this problem, we have developed a new technique for solving high-index problems by combining symbolic and numerical methods. Numerical tests indicate that the method yields results with an accuracy comparable to that obtained for the corresponding state-space ODE.

Step Length Adjustment

Researchers: Kjell Gustafsson in cooperation with Gustaf Söderlind (Dept of Numerical Analysis)

When implementing a numerical algorithm it has to be equipped with supervisory code that acts as a safety net. This code chooses parameters and handles exceptional cases in such a way that the algorithm runs smoothly and produces a correct result. Using analogies from automatic control the supervisory code can be regarded as a controller with the numerical algorithm as the controlled process.

In the case of numerical integration of ordinary differential equations the control objective is to produce a sufficiently accurate solution with the least amount of computation. An important control variable is the stepsize which directly affects the integration error. Traditionally, the same stepsize selection rule is used for all integration methods. However, different methods have different properties and using the insight provided by the control analysis it is possible to improve on the stepsize controller.

Recently, the research has been aimed at control of implicit methods. An implicit method includes an equation solver, which the controller

has to supervise. The interaction between the different loops complicates the control design.

Applications

The major application projects are knowledge-based control systems, robotics, and power systems.

Knowledge-Based Control

Researchers: Karl-Erik Årzén, Tore Hägglund, Jan Eric Larsson

The department is a part of the IT4 project "Knowledge-based real-time control systems" together with ABB. The aim of the project is to specify and verify a system architecture that integrates knowledge-based techniques with conventional distributed control systems. The concept is based on a common knowledge base containing an object-oriented multi-level, multi-view model of the process and the control system. The UHT sterilization process Steritherm from Alfa Laval is used as a demonstrator.

Two prototypes have been developed. One uses hypermedia techniques to emulate the operator interface of a knowledge-based control system. This prototype is implemented in the hypermedia tool Plus on an Apple Macintosh II computer. The second prototype uses the real-time expert system tool G2 to explore the internal structure of the knowledge base. The G2 prototype consists of two main parts: a real-time Steritherm simulator and a model of a knowledge-based control system that controls and monitors the simulation model. The control system includes continuous PID control, sequential control, alarm logic, rule-based monitoring, model-based on-line diagnosis based on quantitative governing equations, model-based on-line diagnosis based on signed digraphs, fault tree based off-line alarm analysis, production scheduling, and a product following system. The production scheduling part was developed by Marcel Schoppers from Advanced Decision Systems who participated in the project between

February – May 1991. The use of the functional modeling methodology Multi-level Flow Models (MFM) developed by Morten Lind as a base for diagnosis schemes is being explored by Jan Eric Larsson. A toolbox for coloured Petri nets was developed by Patrick Sarraut from University of Grenoble.

Robotics and Sensory Control

Researchers: Lars Nielsen, Ola Dahl, Klas Nilsson

A laboratory for robotics and sensory control has been established. The responsible researcher is Lars Nielsen. The experimental work is centered around an Asea Irb-6 robot. Hardware interfaces have been developed to create an open system suitable for control experiments. Other experimental setups are a separate Asea Irb-6 DC-servo motor with the same interfaces, and setups around different versions of a DC-servo developed at the department. 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. For the real-time control, we use software mainly based on the languages Modula-2 and C++, and a real-time programming environment developed at the department. Further, a system for automatic generation of code for control algorithms and a system for interfacing Matlab to the real time environment have been developed and used. Using this environment a number of projects and prototype systems have been tested in research, education and master theses work.

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. Typical applications are gluing, arc welding, and laser cutting. A feedback scheme for path following by trajectory time scaling has been developed. The scheme is used in execution of fast trajectories along a geometric path, where the motion is limited by torque constraints. The time scaling is done by using a secondary controller that modifies a nominal trajectory during motion. A key

idea is that a scalar quantity, the path acceleration, is modified, resulting in coordinated adjustment of the individual joint motions. The functionality of the secondary controller is verified by simulations and experiments.

The addition of a vision sensor can provide extra information in sensor based path following, but the computation time is crucial to make feedback action possible. We have developed new ideas for efficient computational schemes for different calibration problems by using novel geometric concepts called shape and mutual cross-ratios.

Another main project is on the structure 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. One aim is to provide a layer between a supervisory sequence control layer and the basic control level.

Other projects include controllability issues of robots in singular configurations, identification of robot parameters from real data, experiments with adaptive control of the Asea Irb-6 robot, kinematic calibration, alarm prediction, projective area-invariants, and implementation of a simple neuron servo.

Power Systems

Researchers: Bo Eliasson, Sven Erik Mattsson, Lars Rundqwist

Self-excited low frequency power oscillations in large power systems may jeopardize the operation of the systems. The problem is to model the large systems and to decide where to place the damping equipment. Design methods are tested on models of the Nordic power system. The load model has a great influence on the resulting controller. Further work on siting and tuning of power system stabilizers has been done and the methods are demonstrated on a 244 machine model of the Nordic power system. These results were presented in the thesis by Eliasson (TFRT-1032).

A new cooperation has started together 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. The models can be used for design, simulation, and documentation.

Control of Biotechnology Processes

Researchers: Per Hagander in cooperation with Olle Holst and Bo Mathiasson (Biotechnology, Lund)

A joint project with the Division of Biotechnology, Chemical Center, Lund, on control in biotechnology processes has been funded by STU since 1983. Measurement of ethanol concentration is used in fed-batch production of baker's yeast. The process dynamic changes during a batch, but the main control problem is to follow the feed demand increasing with the exponential growth rate μ. It is found advantageous to substitute the I-part of a PID-regulator with an unstable part with a pole at μ using a reduced order observer. The D-part can be tuned for robustness. In certain situation μ may change, and an adaptive observer tracking such changes is shown to improve the control. Some optimal control problems are also formulated and investigated using nonlinear control theory.

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. The new regulator with an unstable load model is also successfully tested.

Modeling and Control in Medical Systems

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

Two projects treat estimation of parameters and modeling of human posture dynamics. The work is sponsored by the Swedish Medical Research Council (MFR) and Söderbergs Foundation. The stability investigation is made with induced body sway by galvanic or vibratory stimuli followed by analysis with application of methods from signal processing and control theory. The goal is to find parameters that describe the human ability to maintain posture. The methods developed are intended for use in diagnosis and rehabilitation of human balance disorders.

5. Dissertations

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

Damping of Power Oscillations in Large Power Systems

Bo Eliasson
PhD dissertation, 28 September 1990

Many of the power systems of today are probably the largest MIMO-systems (Multi Input Multi Output) ever built by mankind. Much research has been done during the last twenty years about tuning of damping equipment in power systems. Damping equipment of concern in this thesis are PSSs (Power System Stabilizers), SVCs (Static Var Compensators), and HVDC (High Voltage Direct Current) links. A large number of design techniques have been presented, from conventional SISO-design (Single Input–Single Output), root-loci design to modern techniques such as LQ-design and MIMO-techniques. Unfortunately, the existing control design techniques cannot cope with large power systems, which models typically have more than 2000 states. Either the techniques are too time consuming for the designer or the computational demand is far beyond the capacity of modern computers. Another important feature, which seldom is included in the models or the design procedures, is the characteristics of the load. Especially the voltage dependence of the load has a major impact on the performance and tuning of parameters concerning the PSSs and the SVCs. The frequency dependence of the load becomes important for the HVDC links. This thesis focuses on four major topics:

(1) Modeling of a large power system with respect to slow oscillations (two states/generator); (2) Aggregation of large power systems with preservation of the slow dynamics; (3) Finding proper feedback structures for the different damping equipment for the siting and tuning analysis; (4) Formulation of an optimization problem for tuning of control parameters applicable to damping equipment in a large power system.

Only slow and system wide modes are of concern in this thesis, i.e. modes with a frequency less than about 0.8 Hz. Faster modes are rather well damped due to the damper windings in the generators. At the most a three state concept for damping is enough. For slow modes, though, a two state concept is enough, which is also pointed out in this thesis. The optimization problem is tested for 200 parameters and the tuning works well. This amount of parameters covers the need of tuning of slow modes in a large power system.

Anti-Reset Windup for PID Controllers

Lars Rundqwist
PhD dissertation, 29 May 1991

Reset windup or integrator windup is a well-known problem arising in controllers with integral action and actuator nonlinearities. Saturations, i.e., constraints in magnitude and rate of the actuator are common actuator nonlinearities. Other examples are backlash and hysteresis. Consequences of these nonlinearities are controller windup, instability, and limit cycles. In general, windup denotes an undesirable transient in the process output. In case of instability or limit cycles the process output grows towards infinity or some boundary, or it oscillates with a constant nonzero amplitude. Anti-windup (or anti-reset windup) denotes precautions in the controller to protect it from winding up.

A survey over different methods of handling control systems with saturations is given. The survey includes a classification and unification of many published methods.

The thesis is focused on proportional-integral-derivative (PID) controllers and their anti-windup. The reason for specializing on PID controllers is that they are the most common controllers. Further, all aspects of anti-windup in PID controllers are not yet fully understood. Usually, the anti-windup is tuned or derived to handle setpoint changes but in the thesis PID anti-windup is treated for disturbances. Closed-loop stability for PID controllers with anti-windup is also treated.

The main results in the thesis are design rules for anti-windup methods for PID controllers. It is clearly demonstrated that the responses to measurement noise and impulse disturbances to the process are sensitive to the choice of anti-windup parameters. Responses to setpoint changes and load disturbances are much less sensitive and, most important, they are well behaved when anti-windup is well chosen with respect to measurement noise and impulse disturbances. The design rules are evaluated on a number of processes.

6. Looking Back

There is currently a debate on the industrial impact of university research. This requires of course a reasonable time perspective. To provide some input to this discussion we will lock back on some earlier projects and evaluate their impact. In this year's report we will discuss research on control of heating, ventilation and air conditioning systems that was done at the department in the seventies. The activity started in the late sixties and was finished in 1980.

The project was originally supported by STU. It began by establishing a network of contacts with industrial partners like Billman-Regulator AB, Honeywell AB, Hugo Theorells Ingenjörsbyrå AB, Landis & Gyr, Orrje & Co – Skandiakonsult, and Tour & Andersson AB. A large number of master thesis projects were carried out in order to develop mathematical models based on physics and system identification experiments. Preliminary investigation of control algorithms were also carried out. We also collaborated in continued education courses given by Svenska Teknologföreningen to improve and strengthen our network. Based on the early results a research project "Digital Control of Heating Ventilation and Air Conditioning (HVAC) Systems" was formulated in collaboration with the Department of Building Science at LTH. Funding was provided by BFR (Swedish Council for Building Research). Professor K. J. Åström acted as principal investigator and a PhD student, Lars Jensen was the project leader. Significant contributions were also given by many master's students. The project was started in 1970. The key idea was to explore the use of computer control for HVAC systems. The main results of the project were:

- A new experimental technique to perform measurements and control experiments remotely.
- Demonstration of the superior performance of computer control.

- Software for real-time control IPCL.
- Transfer of results to a Swedish company that quickly gained dominating market share.

The major disappointment in the project was that we were unable to persuade the governmental agency responsible for the building code to stipulate good acceptance procedures for control systems in buildings. Without a proper code it is difficult for high quality systems to be competitive to the detriment of consumers.

More information about the project is found in our activity reports for the years 1968 to 1978, report numbers TFRT–4001 to TFRT–4010, which also contain appropriate references.

During the project many experiments were carried out in several buildings far away from Lund. These experiments were quite time consuming. At the the time of the project, computers were scarce, expensive and bulky. It was not economical to acquire a process computer and to move it to the different buildings. Instead we used a process computer at the Department of Automatic Control, a PDP 15. Using a special coupler controller device this computer was connected to the different buildings over the telephone net. It was possible to execute experiments automatically. This experimental setup turned out to be very efficient. It was used to test many different control algorithms and also to do long term evaluation of performance of the systems. Experiments were performed for more than 1000 hours with the automatic system.

Heating ventilation and air-conditioning systems are to some extent nonlinear, their characteristics change significantly with seasons and operating conditions. Equipment like valves and systems are cheaper than corresponding equipment used in the process industry. This means that imperfections in actuators like backlash, friction and hysteresis are quite severe. It was demonstrated that computer controlled systems could deal quite well with these problems. Experiments with unconventional control algorithms were also performed.

Interactive real-time software for implementing computer controlled systems were developed including a new interactive language IPCL.

Significant efforts were made to transfer the results to industry. Collaboration was made with a small startup company Carl Olin Elektronik AB in Lund. In 1975 Lars Jensen started to work half time for them. A computer-controlled system, System 6000, based on a Data General Minicomputer Nova was developed. A typically configuraton had 32 kbyte of core memory and about 100 analog inputs and 100 digital outputs. The language IPCL was an important part of the new system. It permitted very simple commissioning and on-line modification of the system. In 1975 part of Carl Olin's company was acquired by Tour & Andersson AB, who developed a new centralized system DDC 6. The remaining part of Olin's company was acquired by Tour & Andersson AB in 1977, who formed TAIAB (Tour & Andersson Industri AB).

A new System 7 was announced in 1984. This system, which has undergone several revisions, is still marketed. A modified version of IPCL is still part of the system. TAIAB now has about 25% market share in Sweden and 20% market share in Scandinavia.

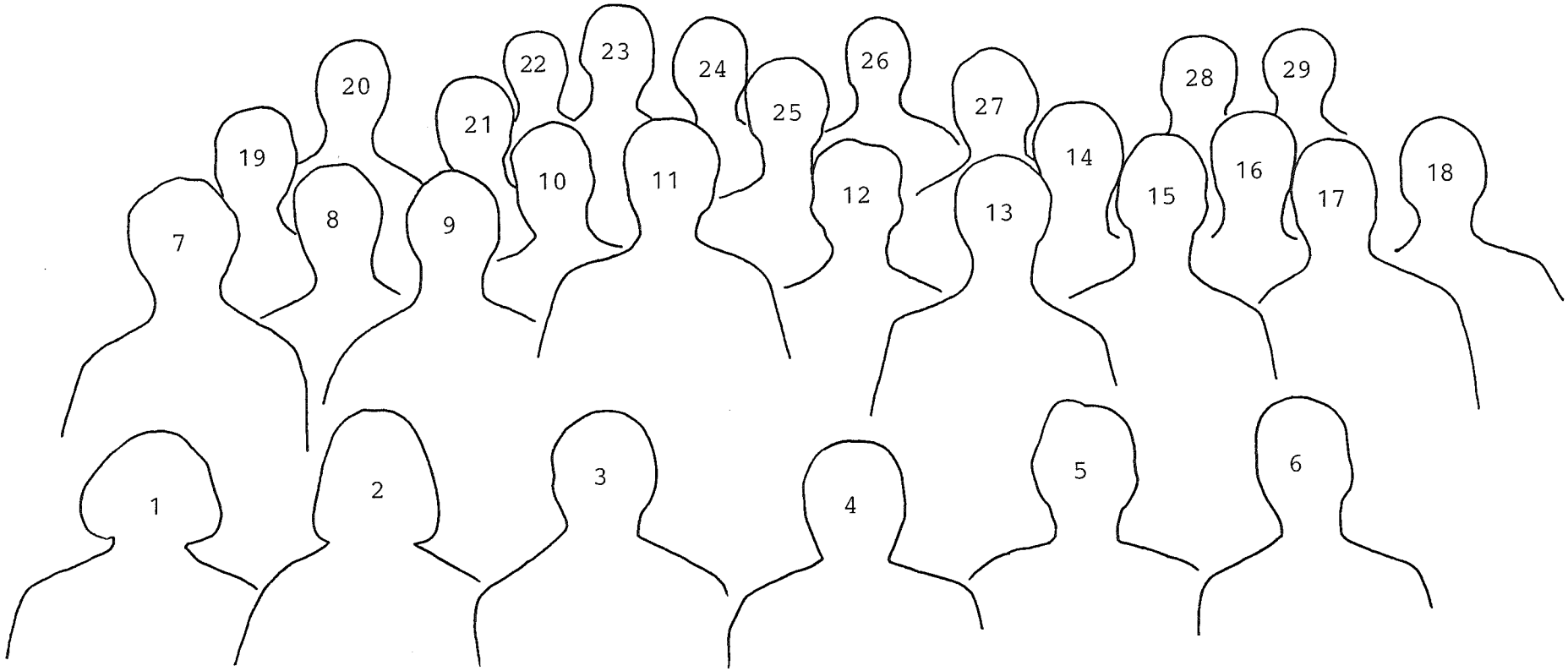
Lars Jensen continued his part time employment. In May 1978 he completed his PhD dissertation and in April 1980 he became professor at the Department of Building Science, LTH. The project was then transferred to that department.

This project illustrates that basic engineering research can have a significant industrial impact. The theme of the project was that HVAC systems were good candidates for computer control. Apart from research competence, the key factors that contributed to the success were:

- A good awareness of development of technology.
- Good industrial contacts were established at an early stage.
- Significant attention was given to the transfer of technology.

At the start of the project computers were much too expensive to be applied to HVAC systems. There were, however, good indications that the prize performance ratio would decrease significantly. The fact that Lars Jensen left his university position to work part time in industry was a key factor in transferring the results to industry.

It is an educated guess that the time now is ripe for a second look at control problems in HVAC systems.



The group photo below was taken in August 1991 and shows most of our members.

1. Agneta Tuszynski, 2. Eva Dagnegård, 3. Björn Wittenmark, 4. Karl Johan Åström, 5. Eva Schildt, 6. Britt-Marie Mårtensson, 7. Rolf Braun, 8. Henrik Olsson, 9. Sven Erik Mattsson, 10. Ulf Jönsson, 11. Per Hagander, 12. Bernt Nilsson, 13. Per Persson, 14. Lars Nielsen, 15. Anders Blomdell, 16. Leif Andersson, 17. Ola Dahl, 18. Klas Nilsson, 19. Michael Lundh, 20. Kjell Gustafsson, 21. Tore Hägglund, 22. Ulf Holmberg, 23. Dag Brück, 24. Bo Bernhardsson, 25. Anders Hansson, 26. Tomas Schönthal, 27. Karl-Erik Årzén, 28. Rolf Johansson, and 29. Per-Olof Källén.

Missing: Mats Andersson, Jan Eric Larsson, Mats Lilja, and Lars Rundqwist.

A. List of Personnel

The following list shows the status of June 1991 if nothing else is mentioned.

Professorer (Professors)

Karl Johan Åström
Björn Wittenmark

Högskolelektorer (Associate professors)

Per Hagander
Tore Hägglund
Rolf Johansson
Lars Nielsen

Forskarassistent (Research associate)

Sven Erik Mattsson

Forskningsingenjörer (Research engineers)

Leif Andersson
Anders Blomdell
Rolf Braun
Tomas Schönthal

Forskningsassistenter (Research assistants)

Karl-Erik Årzén
Dag Brück
Ulf Holmberg
Ulf Jönsson
Per-Olof Källén
Mats Lilja

Klas Nilsson
Henrik Olsson
Per Persson
Lars Rundqwist

Doktorandtjänster (Teaching assistants)

Mats Andersson
Bo Bernhardsson
Ola Dahl
Kjell Gustafsson
Anders Hansson
Jan Eric Larsson
Michael Lundh
Bernt Nilsson

Institutionssekreterare (Secretaries)

Eva Dagnegård (part time)
Eva Schildt
Agneta Tuszynski (part time)

Assistent (Technical drawings)

Britt-Marie Mårtensson

Visiting Scientists

Mr Javier Serrano
Universitat Autonoma de Barcelona, Spain
(10 Jan – 20 Sept 1990)

Mr Stéphane Sallé
Laboratoire d'Automatique de Grenoble
ENSIEG, Grenoble, France
(1–31 Aug 1990)

Mr Ho Weng Khuen
National University of Singapore, Singapore
(28 Sept – 14 Dec 1990)

Mr Marcel Schoppers
Advanced Decision Systems, Mountain View, California
(7 Feb – 31 May 1991)

Mr Patrick Saurrat
Laboratoire d'Automatique de Grenoble
ENSIEG, Grenoble, France
(From 8 April 1991)

Prof Tamer Basar
University of Illinois, Urbana, Illinois
(22–26 April 1991)

Mr Mark Spong
University of Illinois, Urbana, Illinois
(3–31 May 1991)

Dr Jonathan Shopiro
AT&T Unix Software Laboratories, Warren, New Jersey
(4–7 June 1991)

B. Awards

Karl Johan Åström received an IEEE field award in December 1990. The award is called *IEEE Control Systems Science and Engineering Award* and is given because of "meritorious achievement in contributions to theory, design or techniques as evidenced by publications or patents in the area of control systems science and engineering". Previous recipients of this award are H. H. Rosenbrock, A. E. Bryson, Jr., G. Zames, C. A. Desoer, W. M. Wonham, D. C. Youla, and Y. C. Ho.

Kjell Gustafsson and **Lars Rundqwist** were two out of five finalists in the *Young Author Prize* competition at the 11th IFAC World Congress in Tallinn, Estonia, in August 1990. Their contributions were the papers "Using Control Theory to Improve Stepsize Selection in Numerical Integration" and "Anti-reset Windup for PID Controllers", respectively.

Jan Eric Larsson received the *SAAB-Scania Research Award* in May 1991.

Björn Wittenmark was elected *IEEE Fellow* with the citation: "For contributions to adaptive control and to the development of self-tuning regulators".

C. External Publications

Books

Hägglund, Tore. Process Control in Practice. Chartwell-Bratt Ltd, Bromley, UK, 1991.

Papers

Åström, Karl Johan. "Adaptive control." In Festschrift for Dr. R. E. Kalman on his 60th birthday. Springer Verlag, 1990.

Åström, Karl Johan. "Assessment of achievable performance of simple feedback loops." International Journal of Adaptive Control and Signal Processing, **5**, pp. 3–19, 1991.

Åström, Karl Johan and Hermann Steingrímsson. "Implementation of a PID controller on a DSP." In Ahmed, Ed., Digital Control Applications with the TMS 320 Family. Texas Instruments, 1991.

Canudas de Wit, Carlos, Karl Johan Åström, and N. Fixot. "Computed torque control via a nonlinear observer." International Journal of Adaptive Control and Signal Processing, **4**, pp. 443–452, 1990.

Dahl, Ola and Lars Nielsen. "Torque limited path following by online trajectory time scaling." IEEE Transactions on Robotics and Automation, **6**, pp. 554–561, 1990.

DeWeerth, Steve, Lars Nielsen, Carver Mead, and Karl Johan Åström. "A simple neuron servo." IEEE Transactions on Neural Networks, **2**, pp. 248–251, 1991.

Hagander, Per and Bo Bernhardsson. "On the notion of strong stabilizability." IEEE Transactions on Automatic Control, **AC-35:8**, pp. 927–929, 1990.

Hägglund, Tore and Karl Johan Åström. "Industrial adaptive controllers based on frequency response techniques." Automatica, **27**, pp. 599–609, 1991.

Hang, C. C., Karl Johan Åström, and Weng Kuen Ho. "Refinements of the Ziegler-Nichols tuning formula." IEE Proceedings-D, **138:2**, pp. 111–118, 1991.

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

Johansson, Rolf. "Quadratic optimization of motion coordination and control." IEEE Transactions on Automatic Control, **AC-35:11**, pp. 1197–1208, 1990.

Johansson, Rolf. "Optimal coordination and control of posture and locomotion." Mathematical Biosciences, **103**, pp. 203–244, 1991.

Johansson, Rolf. "Binäre Steuerungstechnik – Eine Einführung by K. H. Fasol." Automatica, **27**, pp. 210–211, 1991.

Johansson, Rolf and Måns Magnusson. "Lateral posture stability during galvanic stimulation." Acta Otolaryngologica, **481**, pp. 585–588, 1991.

Magnusson, Måns, M. Karlberg S. Padouan, and Rolf Johansson. "Delayed onset of ototoxic effects of gentamicin in treatment of ménière's disease." Acta Otolaryngologica, **481**, pp. 610–612, 1991.

Magnusson, Måns, Rolf Johansson, and J. Wiklund. "Galvanically induced body sway in the anterior-posterior plane." Acta Otolaryngologica, **481**, pp. 582–584, 1991.

Steingrímsson, Hermann and Karl Johan Åström. "DSP implementation of a disk drive controller." In Ahmed, Ed., Digital Control Applications with the TMS 320 Family. Texas Instruments, 1991.

Conference Papers

Andersson, Mats, Sven Erik Mattsson, and Bernt Nilsson. "A kernel for object-oriented CACE." In Proceedings of the Nordic CACE Symposimum, Lyngby, Denmark, 1990.

Årzén, Karl-Erik, C. Rytoft, and C. Gerding. "A knowledge-based control system concept." In Proceedings of the 1990 European Simulation Symposium, Ghent, Belgium, 1990. SCS International.

Årzén, Karl-Erik. "A sequential function chart toolbox." In Proceedings of the First European G2 Users Meeting, Munich, Germany, 1990. Gensym Corp.

Årzén, Karl-Erik. "Knowledge based applications in the process industry: Current state and future directions." In Proceedings of the IFAC Workshop on Computer Software Structures Integrating AI/KBS in Process Control, Bergen, Norway, 1991.

Åström, Karl Johan. "A response from academia." In Preprints IFAC Conference on Advances in Control Education, pp. 7–12, Boston, Massachusetts, 1991.

Åström, Karl Johan. "Directions in intelligent control." In IFAC International Symposium on Intelligent Tuning and Adaptive Control (ITAC 91), Singapore, 1991.

Åström, Karl Johan. "Use gainschedule for process control." In Proceedings of the 11th IFAC World Conference, Tallinn, Estonia. Pergamon Press, 1991.

Åström, Karl Johan. "Education in automatic control at Lund Institute of Technology." In Proceedings of the 1991 American Control Conference, pp. 306–311, Boston, Massachusetts, 1991.

Åström, Karl Johan and Mats Lilja. "Control design for a dynamic vehicle." In Proceedings of the 1991 American Control Conference, pp. 2969–2974, Boston, Massachusetts, 1991.

Axelsson, Jan Peter and Per Hagander. "Control design for a bilinear system. Reachable sets and exact linearization." In Proceedings of the 29th IEEE Conference on Decision and Control, Honolulu, Hawaii, 1990.

Bernhardsson, Bo. "The predictive first order hold circuit." In Proceedings of the 29th IEEE Conference on Decision and Control, pp. 1890–1891, Honolulu, Hawaii, 1990.

Dahl, Ola. "Path following for a flexible joint robot." In Proceedings Robotikdagar, Linköping, Sweden, 1991.

Gustafsson, Kjell. "Using control theory to improve stepsize selection in numerical integration of ODE." In Preprints 11th IFAC World Congress, Tallinn, Estonia, 1990.

Gustafsson, Kjell, Michael Lundh, and Mats Lilja. "A set of MATLAB routines for control system analysis and design." In Preprints IFAC Conference on Advances in Control Education, Boston, Massachusetts, 1991.

Hagander, Per, Jan Peter Axelsson, and O. Holst. "Substrate control of biotechnical fedbatch processes. Robustness and the role of adaptivity." In Preprints 11th IFAC World Congress, Tallinn, Estonia, 1990.

Hägglund, Tore and Karl Johan Åström. "A frequency domain approach to adaptive control." In Preprints 11th IFAC World Congress, volume 4, pp. 265–270, Tallinn, Estonia, 1990.

Hansson, Anders and Lars Nielsen. "Control and supervision in sensor-based robotics." In Proceedings Robotikdagar, Linköping, Sweden, 1991.

Holmberg, Ulf. "On identifiability of dissolved oxygen concentration dynamics." In IAWPRC's 25th Anniversary Conference and Exhibition, Kyoto, Japan, 1990.

Johansson, Rolf. "Real-time identification of multilinear systems." In Preprints 11th IFAC World Congress, Tallinn, Estonia, 1990.

Johansson, Rolf and Måns Magnusson. "Optimal coordination and control of posture and locomotion." In Brandt et al., Eds., Disorder of Posture and Gait 1990, pp. 29–31. Georg Thieme Verlag, Stuttgart–New York, 1990.

Johansson, Rolf and Måns Magnusson. "Optimal coordination and control of posture and locomotion." In Simula, Ed., Proceedings of the Int. Conf. on Artificial Neural Networks Espoo, Finland, 1991. Elsevier Science Publishers, 1991.

Kuipers, Benjamin and Karl Johan Åström. "The composition of heterogeneous control laws." In Proceedings of the 1991 American Control Conference, pp. 630–636, Boston, Massachusetts, 1991.

Larsson, Jan Eric. "FREX—An expert system for frequency response analysis." In Preprints 11th IFAC World Conference, volume 7, pp. 45–49, Tallinn, Estonia, 1990.

Larsson, Jan Eric. "A multilevel flow model of Steritherm." In Proceedings of the 1990 European Simulation Symposium, pp. 16–20, Ghent, Belgium, 1990.

Larsson, Jan Eric. "A multilevel flow model of Steritherm." In Proceedings of the Nordic CACE Symposium, Lyngby, Denmark, 1990. Technical University of Denmark.

Larsson, Jan Eric. "Model-based fault diagnosis using MFM." In Proceedings of SAIS '91, Uppsala, Sweden, 1991. Computer Science Department, Uppsala University.

Lilja, Mats. "A frequency domain method for low order controller design." In Preprints 11th IFAC World Conference, volume 2, pp. 185–190, Tallinn, Estonia, 1990.

Lilja, Mats and Karl Johan Åström. "An approximate pole placement approach." In Proceedings of the 1991 American Control Conference, pp. 1931–1932, Boston, Massachusetts, 1991.

Lundh, Michael. "Optimization based robust design of uncertain SISO systems." In Preprints 11th IFAC World Congress, volume 5, pp. 260–265, Tallinn, Estonia, 1990.

Lundh, Michael. "A package for laboratory experiments in discrete time control." In Preprints IFAC Conference on Advances in Control Education, Boston, Massachusetts, 1991.

Magnusson, Måns and Rolf Johansson. "Dynamic postural control in subjects with an acoustic neurinoma." In Haid, Ed., Vestibular Diagnosis and Neuro-Otosurgical Management of the Skull Base, pp. 86–89. Demeter Verlag GmbH, Erlangen, Germany, 1991.

Magnusson, Måns, H. Enbom, R. Johansson, and I. Pyykkö. "The importance of somatosensory information from feet in postural control in man." In Brandt et al., Eds., Disorder of Posture and Gait 1990, pp. 190–193. Georg Thieme Verlag, Stuttgart–New York, 1990.

Mattsson, Sven Erik and Mats Andersson. "A kernel for system representation." In Preprints 11th IFAC World Congress, volume 10, pp. 91–96, Tallinn, Estonia, 1990.

Nielsen, Lars and Gunnar Sparr. "Efficient establishment of correspondences from affine shape indexing," (Swedish association for pattern recognition). In Symposium SSAB (Svenska Sällskapet för Automatiserad Bildanalys), pp. 120–123, Stockholm, Sweden, 1991.

Nielsen, Lars and Gunnar Sparr. "Detection and localization based on area-invariants." In Invariants Workshop, Reykjavik, Iceland, 1991. Invited paper.

Nielsen, Lars, Carlos Canudas de Wit, and Per Hagander. "Controllability issues of robots near singular configurations." In Preprints of the 2nd International Workshop on Advances in Robot Kinematics, Linz, Austria, 1990.

Nielsen, Lars, Carlos Canudas de Wit, and Per Hagander. "Controllability issues of robots near singular configurations." In Preprints of the International Workshop in Adaptive and Nonlinear Control: Issues in Robotics, Grenoble, France, 1990.

Nielsen, Lars, Carlos Canudas de Wit, and Per Hagander. "Controllability issues of robots in singular configurations." In IEEE Int. Conference on Robotics and Automation, Sacramento, California, 1991.

Nilsson, Bernt. "Modelling of sugar crystalization process." In Preprints of the DUP Conference 1990, Stockholm, Sweden, 1990. STU.

Nilsson, Bernt. "Object-oriented modelling of a controlled chemical process." In Preprints 11th IFAC World Congress, volume 10, pp. 22–27, Tallinn, Estonia, 1990.

Nilsson, Bernt. "Modelling and simulation of sugar crystalization process." In Preprints of the DUP conference 1991, Stockholm, Sweden, 1991. STU.

Rundqwist, Lars. "Anti-reset windup for PID controllers." In Preprints 11th IFAC World Congress, Tallinn, Estonia, 1990.

Sallé, Stéphane E. and Karl Johan Åström. "Synthesis of a smart PID controller using expert system techniques." In Proceedings IFAC International Symposium on Intelligent Tuning and Adaptive Control (ITAC 91), Singapore, 1991.

Schaub, T. and Anders Hansson. "Frame synchronization for spontaneous transmissions." In IEEE Global Telecommunications Conference & and Exhibition—Conference Record, San Diego, California, 1990.

Sparr, Gunnar, Lars Nielsen, and C.-G. Werner. "Analytic and geometric image modelling," (Swedish association for pattern recognition). In Symposium SSAB (Svenska Sällskapet för Automatiserad Bildanalys), pp. 66–70, Stockholm, Sweden, 1991.

Wittenmark, Björn. "On the choice of design method in adaptive control." In Proceedings of the 29th IEEE Conference on Decision and Control, volume 2, pp. 319–320, Honolulu, Hawaii, 1990.

Wittenmark, Björn and Karl Johan Åström. "Some aspects on pole-placement design." In Preprints 11th IFAC World Congress, volume 2, pp. 167–172, Tallinn, Estonia, 1990.

Technical Reports

Larsson, Jan Eric, Ed. "Projekt i tillämpad AI 1989," (Projects in applied AIxs 1989). Internal report LU-CS-IR: 90.1, Department of Computer Science, Lund Institute of Technology, Lund, Sweden, 1990.

D. Reports

The reports listed below are numbered with "TFRT-" and four numerals. This number is part of the complete report number CODEN: LUTFD2/(TFRT-0000).

PhD Theses

Eliasson, Bo. Damping of Power Oscillations in Large Power Systems, PhD thesis TFRT-1032. May 1990.

Rundqwist, Lars. Anti-Reset Windup for PID Controllers, PhD thesis TFRT-1033. March 1991.

Final Reports

Dagnegård, Eva and Tore Hägglund. "Activity report 1989–1990." Report TFRT-4018, September 1990.

Nilsson, Bernt. "En on-linesimulator för operatörsstöd," (An on-line simulation for operator support). Report TFRT-3209, May 1991.

Master Theses

Abrahamsson, Per and Peter Hallgren. "Rekursiv identifiering av dynamiska egenskaper för stabilitetsmonitering," (Recursive identification of boil water reactor dynamics for stability supervision). Master thesis TFRT-5439, June 1991.

Andersson, Marie. "A process knowledge base browser." Master thesis TFRT-5435, March 1991.

Bengtsson, Jörgen. "Transientanalys," (Transient response analysis). Master thesis TFRT-5438, June 1991.

Bergman, Gustav and Christian Söderberg. "A reasoning machine generator for object-oriented programming languages." Master thesis TFRT-5429, December 1990.

Ekblad, Dan and Johan Mercke. "Reglering av autoklav," (Automatic control of sterilizer). Master thesis TFRT-5431, January 1991.

Fransson, Per-Anders and Patrik Sundström. "Visual contribution in human postural control." Master thesis TFRT-5436, February 1991.

Fredriksson, Katarina. "Identifiering av öppet system ur experiment utförda under återkoppling," (Identification of open loop system based on experiments performed in closed loop). Master thesis TFRT-5433, February 1991.

Göransson, Åsa. "Eine Methode zur Adaptiven Regelung ohne Persistent Excitation," (Method for adaptive control without persistent excitation). Master thesis TFRT-5437, December 1990.

Hermodsson, Frans and Lars Bergenzaun. "Finjustering av styrsimulator," (Improvement of man-machine of the steering gear in a submarine). Master thesis TFRT-5430, November 1990.

Möhle, Marco. "Jämförelse mellan en PID-regulator och novatune," (Comparison between a PID regulator and Novatune). Master thesis TFRT-5427, December 1990.

Mattsson, Ola. "An expert system for ÖSI." Master thesis TFRT-5428, December 1990.

Mattsson, Ulf. "Digital reglering med signalprocessorer och C++," (Digital control using digital signal processors and C++). Master thesis TFRT-5434, February 1991.

Nilsson, Patrik and Leif Nilsson. "Snabb mätvärdesinsamling med en IBM AT," (Fast sampling using the IBM AT). Master thesis TFRT-5426, October 1990.

Nilsson, Peter. "Programmoduler för styrning och identifiering av en industrirobot," (Software modules for control and identification of an industrial robot). Master thesis TFRT-5432, March 1991.

Szabó, Tomas. "Evaluation of the unidraw framework for interactive object editors." Master thesis TFRT-5425, August 1990.

Internal Reports

Åström, Karl Johan and Hermann Steingrímsson. "Implementation of a PID controller." Report TFRT-7466, October 1990.

Bernhardsson, Bo. "The predictive first order hold circuit." Report TFRT-7458, July 1990.

Braun, Rolf, Lars Nielsen, and Klas Nilsson. "Reconfiguring an ASEA IRB-6 robot system for control experiments." Report TFRT-7465, October 1990.

Brück, Dag. "ANSI C++ committee meeting July 9–13, 1990." Report TFRT-7459, August 1990.

Brück, Dag. "ANSI C++ committee meeting November 12–16, 1990." Report TFRT-7471, December 1990.

Gustafsson, Kjell. "Logger—A program for data logging." Report TFRT-7457, July 1990.

Gustafsson, Kjell and Bo Bernhardsson. "Control design for two lab-processes: The flexible servo, the fan and the plate." Report TFRT-7456, July 1990.

Gustafsson, Kjell and Per Hagander. "Discrete-time LQG with cross-terms in the loss function and the noise description." Report TFRT-7475, April 1991.

Gustafsson, Kjell, Mats Lilja, and Michael Lundh. "A collection of Matlab routines for control system analysis and synthesis." Report TFRT-7454, July 1990.

Gustafsson, Kjell, Mats Lilja, and Michael Lundh. "A collection of Matlab routines for control system analysis and synthesis—The code." Report TFRT-7455, July 1990.

Hagander, Per and Bo Bernhardsson. "Structure of H_∞ optimal controllers. The golden section example." Report TFRT-7468, October 1990.

Hansson, Anders. "Optimal controllers for an integrator with load disturbance." Report TFRT-7464, September 1990.

Hansson, Anders. "Alternative to minimum variance control." Report TFRT-7474, February 1991.

Ho, Weng Kuen. "Tuning of PI controllers for processes with integration based on gain and phase margin specifications." Report TFRT-7472, December 1990.

Johansson, Rolf, Bo Bernhardsson, and Ola Dahl. "Processidentifiering – Projektarbeten hösten 1990," (Process identification—Project work autumn 1990). Report TFRT-7473, December 1990.

Larsson, Jan Eric. "An expert system for frequency response analysis." Report TFRT-7469, November 1990.

Larsson, Jan Eric. "Model-based alarm analysis using MFM." Report TFRT-7470, January 1991.

Mattsson, Sven Erik. "Index reducation in differential-algebraic equations using dummy derivatives." Report TFRT-7477, June 1991.

Nielsen, Lars. "Computer implementation of control systems." Report TFRT-7476, May 1991.

Rundqwist, Lars. "Anti-reset windup for PID controllers." Report TFRT-7461, August 1990.

Sallé, Stéphane and Karl Johan Åström. "Smart synthesis of a PID controller." Report TFRT-7462, August 1990.

Serrano, Javier. "Robust adaptive control: Estimator implementation." Report TFRT-7463, September 1990.

Steingrímsson, Hermann and Karl Johan Åström. "DSP implementation of a disk drive controller." Report TFRT-7467, October 1990.

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E. Seminars at the Department

Seminars given at the department during the academic year 1990–1991, are summarized here. They are given both by the staff at the department and by invited lecturers.

1990

Aug 23	Tomas Halling and Tomas Zeidler: "Modeling and simulation of a crossflow heat exchanger." MSc-thesis presentation.
Aug 23	Mats Lilja: "A frequency domain method for low order controller design."
Aug 24	Björn Wittenmark: "Some aspects on pole-placement design."
Aug 24	Michael Lundh: "Optimization based robust design of uncertain SISO systems."
Aug 27	Tomas Szabo: "Unidraw, a framework for interactive object editors." MSc-thesis presentation.
Aug 28	Don Wiberg: "A convergent approximation to the optimal parameter estimator."
Aug 29	Per Hagander: "Substrate control of biotechnical fedbatch processes; robustness and the role of adaptivity."
Aug 30	Stéphane Sallé: "Smart synthesis of a PID-controller."
Aug 31	Dag Brück: "Exception handling in C++."
Sep 9	Lars Nielsen: "Controllability issues of robots near singular configurations."

Sep 14 Karl Johan Åström: "Experiences from USA."

Sep 14 Karl Johan Åström: "Introduction to the graduate course in neural nets."

Sep 18 Karl-Erik Årzén: "A Grafcet toolbox in G2."

Sep 21 Jan Erik Larsson and Karl-Erik Årzén: "Report from ECAI'90 in Stockholm and AAAI'90 in Boston."

Sep 25 Robert G. Wilhelm (ABB Process Automation Inc): "An object oriented real time sheet measuring system."

Sep 28 Bo Eliasson: "Damping of power oscillations in large power systems." Doctoral dissertation defence. Opponent: Göran Andersson (KTH, Stockholm).

Oct 12 Ho Weng Khuen: "An implementation of intelligent PID auto-tuning."

Oct 12 Carlos Canudas de Wit (Grenoble): "Advances in Control of mobile robots with nonholonomic constraints."

Oct 12 Carlos Canudas de Wit (Grenoble): "Adaptive robot control via velocity estimated feedback."

Oct 15 Leif Nilsson and Patrik Nilsson: "Fast sampling using the IBM AT." MSc-thesis presentation.

Oct 16 Jan Eric Larsson: "An MFM model of Steritherm."

Oct 19 Boris Tamm (Tallinn, Estonia): "Integrated control system for city water treatment."

Oct 22 Gustav Bergman and Christian Söderberg: "An object-oriented expert system shell in Simula." MSc-thesis presentation.

Oct 26 Judih E. Grass (Bell Labs, Murray Hill): "CIA++: a C++ information abstractor."

Nov 2 Krister Forsman (LiTH, Linköping): "Applications of Gröbner bases in control theory."

Nov 9 Peter Fritzson (LiTH, Linköping): "Semi-automatic debugging and other research activities at the Programming Enviroment Group in Linköping."

Nov 14 Klas Nilsson: "Robots and sensors. An experimental platform."

Nov 28 Ola Mattsson: "An expert system for ÖSI." MSc-thesis presentation.

Dec 12 Mats Lilja: "A graphical method for PID controller design."

Dec 13 Ho Weng Khuen (Univ of Singapore): "Tuning of PI controllers for processes with integration based on gain and phase margin specifications."

Dec 13 Ho Weng Khuen (Univ of Singapore): "The Foxboro exact controller."

Dec 17 Hanspeter Fässler (ABB Robotics): "Modern methods and tools for the mechanical modeling of robots and other multibody dynamic systems."

Dec 17 Hanspeter Fässler (ABB Robotics): "Robot manipulators constrained by stiff contact: Modeling and control of motion and contact forces."

Dec 17 Hanspeter Fässler (ABB Robotics): "A robot ping pong player: Optimized mechanics, high performance 3D vision, and intelligent sensor control."

1991

Jan 11 Steve Murphy (RPI, Troy, New York): "Modeling and simulation of multiple cooperating manipulators on a mobile platform."

Jan 24 Dan Ekblad and Johan Mercke: "Automatic control of sterilizer." MSc-thesis presentation.

Feb 7 Bo Bernhardsson: "Structured stability margin and the finite argument principle."

Feb 12 Anders Ringdahl: "An adaptive toolbox in Matlab." MSc-thesis presentation.

Feb 14 Gunter Stein: "Respect the unstable."

Feb 21 Dag Brück: "Building an object oriented real-time kernel."

Feb 27 Katarina Fredriksson: "Identification of open loop system based on experiments performed in closed loop." MSc-thesis presentation.

April 2 Patrik Sundström and Per-Anders Fransson: "Visuell stimulering av människans balanssystem." MSc-thesis presentation.

April 9 Marcel Schoppers (California): "Real-time AI, part I."

April 12 Videoseminar: "CIRSSE 1990 Status Report." (Video from the robotics lab at RPI.)

April 15 Marcel Schoppers (California): "Real-time AI, part II."

April 16 Anders Hansson: "Alternative to minimum variance control."

April 18 Marcel Schoppers (California): "Real-time AI, part III."

April 19 Anders Wallenborg (Tour & Andersson Innovation AB, Malmö): "A new self-tuning controller for HVAC systems."

April 22–26 Tamer Basar (Univ of Illinois): "H_∞ optimal control: A dynamic game approach." Five seminars short course for graduate students.

April 22 Marcel Schoppers (California): "Real-time AI, part IV."

April 24 Anders Rantzer: "What About Stability of Polytopes of Polynomials?"

April 25 Marcel Schoppers (California): "Real-time AI, part V."

May 7 Mark Spong (Univ of Illinois): "Some remarks on robot dynamics: Hamiltonian mechanics, Riemannian geometry and the network approach to robot control."

May 7 Marcel Schoppers (California): "Real-time AI, part VI."

May 14 Mark Spong (Univ of Illinois): "On the robust control of robots."

May 15 Peter Hallgren and Per Abrahamsson: "On-line identifiering av stabilitetsövervakning av kokvattenreaktor." MSc-thesis presentation.

May 16 Mark Spong (Univ of Illinois): "Robustness of adaptive control of robots: Theory and experiment." (Nationwide video session.)

May 21 Mark Spong (Univ of Illinois): "On force control of robots, part I: Dynamic hybrid control."

May 21 Anders Hansson: "Control and supervision in sensor-based robotics."

May 23 Mark Spong (Univ of Illinois): "On force control of robots, part II: Impedance control and network theory."

May 24 Marcel Schoppers (California): "Real-time AI, part VII."

May 27 Tom Petti (Univ of Delaware): "Hydrogen balance advisory control."

May 29 Lars Rundqwist: "Anti-reset windup for PID controllers." Doctoral dissertation defence. Opponent: W. Schauffelberger (ETH, Zurich).

May 29 W. Schauffelberger (ETH, Zurich): "Educational software for automatic control."

May 30 Jörgen Bengtsson: "Transient response analysis." MSc-thesis presentation.

June 11 Mats Andersson: "Presentation of OmSim."

June 11 Bernt Nilsson: "Modeling and simulation of a sugar crystallization process."

June 12 Ola Dahl: "Optimal control with Maple and Matlab."

June 12 Lars Nielsen: "The course 'Computer implementation of control systems'."

June 17 René Boel (Univ of Gent, Belgium): "Control of communication networks."

June 18 Mats Lilja: "SattLine—An overview."

F. C++ Seminars

C++ is a new programming language that combines support for modern programming methodologies with the efficiency of traditional languages. First introduced in 1985, C++ is based on C with a strong influence from Simula and other well-structured languages. C++ offers better encapsulation and support for abstract datatypes compared to C, plus inheritance which is the foundation of object-oriented programming. C++ has a quickly growing user community and is widely accepted in industry. C++ is used in several projects at the Department of Automatic Control, for example, as implementation language of the prototype developed by the CACE group.

The rapid growth in C++ usage and fear of multiple dialects has spawned an early standardization of the language. The American National Standards Institute (ANSI) formed X3J16 in December 1989 in order to standardize C++. The ISO C++ committee (WG21) was formed in June 1991. A common standard will be developed at joint meetings three times per year. The department is represented in these committees through Dag Brück, who is head of the Swedish delegation. The work is funded by three Swedish companies: ABB Automation, Ericsson and Televerket.

On June 18–19 1991, the department hosted the first ISO WG21 meeting which gathered 12 people representing 7 countries. On June 17–21 1991, the department hosted the ANSI X3J16 meeting with approximately 40 participants, mainly from USA. In connection with these standardization efforts, there was an advanced C++ course on June 4–7 given by Jonathan Shopiro (AT&T Unix System Laboratories) with 41 particpants. There was also a series of C++ seminars held on June 13–14 with an audience of approximately 100 people.

Seminars June 13–14

William M. Miller (Glockenspiel): "C++ Language Overview."

Michael J. Vilot (ObjectWare): "Building Reuseable Components in C++."

Andrew R. Koenig (AT&T Bell Labs): "Templates as Interfaces."

Philippe Gautron (Rank Xerox, France): "Experiences in Using the C++ Task System."

Dmitry Lenkov (Hewlett-Packard): "C++ Symbolic Debugging and Type Identification in C++."

Steven L. Carter (Bellcore): "C++ Standardization."

Susan Waggoner (US West): "Calling on C++—A New Approach to Applications Development."

Jerry S. Schwarz (Lucid): "C++ is Not an Object-Oriented Language."

Michael S. Ball (Taumetric): "Implementing Multiple Inheritance in C++."

Martin J. O'Riordan (Microsoft): "Implementing the Dark Corners of C++."

Bjarne Stroustrup (AT&T Bell Labs): "Sixteen Ways to Stack a Cat."

Richard Holman (Hewlett-Packard): "C++ Development Environments."

William M. Miller (Glockenspiel): "Memory Management Techniques in C++."

G. Lectures by the staff

1990

July 6 — Dag Brück: "Real-time programming in C++," Microtec Research, Santa Clara, California.

July 10 — Per Hagander: "Cultivation of *pseudomonas cepacia* on salicylate. Substrate of a fedbatch process," 5th European Congress on Biotechnology, Copenhagen, Denmark.

July 27 — Karl-Erik Årzén: "Knowledge-based control systems," General Electric, Schenectady.

Aug 1 — Karl-Erik Årzén: "Real-time, process control applications of knowledge-based systems," AAAI Conference, Boston, Massachusetts.

Aug 1 — Karl Johan Åström: "A perspective on automatic control," Dept of Electrical Engineering, National University of Singapore.

Aug 3 — Karl Johan Åström: "Towards intelligent control," Dept of Electrical Engineering, National University of Singapore.

Aug 13 — Karl Johan Åström: "Some aspects on pole-placement design," 11th IFAC World Congress, Tallinn, Estonia.

Aug 13 — Mats Andersson: "A kernel for system representation," 11th IFAC World Congress, Tallinn, Estonia.

Aug 13 — Sven Erik Mattsson: "Object-Oriented Modeling of a Controlled Chemical Process," 11th IFAC World Congress, Tallinn, Estonia.

Aug 13 — Lars Rundqwist: "Anti-reset Windup for PID Controllers," 11th IFAC World Congress in Tallinn, Estonia.

Aug 13 Björn Wittenmark: "Some aspects on pole-placement design," 11th IFAC World Congress, Tallinn, Estonia.

Aug 14 Karl Johan Åström: "Applications of gain scheduling to process control," Introduction to round table discussion, 11th IFAC World Congress, Tallinn, Estonia.

Aug 14 Kjell Gustafsson: "Using Control Theory to Improve Stepsize Selection in Numerical Integration of ODE," 11th IFAC World Congress, Tallinn, Estonia.

Aug 14 Jan Eric Larsson: "FREX–An Expert System for Frequency Response Analysis," 11th IFAC World Conference, Tallinn, Estonia.

Aug 16 Karl Johan Åström: "A frequency domain approach to adaptive control," 11th IFAC World Congress, Tallinn, Estonia.

Aug 16 Per Hagander "Substrate control of biotechnical fedbatch processes. Robustness and the role of adaptivity," 11th IFAC World Congress, Tallinn, Estonia.

Aug 16 Tore Hägglund: "A Frequency domain approach to adaptive control," 11th IFAC World Congress, Tallinn, Estonia.

Aug 17 Michael Lundh: "Optimization based robust design of unvertain SISO systems," 11th IFAC World Congress, Tallinn, Estonia.

Aug 27 Karl Johan Åström: "Frequency response," University of Texas, Austin, Texas.

Sept 2 Rolf Johansson: "Optimal coordination and control of posture and locomotion," Xth International Symposium of the Society for Postural and Gait Research, Munich, Germany.

Sept 3 Karl-Erik Årzén: "Kunskapsbaserade realtidssystem," Realtidssymposium, Linköping, Sweden.

Sept 10 Lars Nielsen: "Controllability Issues of Robots near Singular Configurations," 2nd International Workshop on Advances in Robot Kinematics, Linz, Austria.

Sept 24 Mats Andersson: "An Object-Oriented Modeling Environment for Control Systems Design," Systems Research Center, University of Maryland, College Park, Maryland.

Sept 11 Bo Bernhardsson: "The Game Theory Approach to H-infinity Control," Uppsala, Sweden.

Sept 21 Bo Bernhardsson: "The Game Theory Approach to H-infinity Control," Stockholm, Sweden.

Oct 3 Jan Eric Larsson: "Can Searle think?," Lund University Cognitive Science, Lund, Sweden.

Oct 16 Tore Hägglund: "Perspectives and limitations in adaptive control," the course "District heating plants – Automation and control", the Norwegian Institute of Technology, Trondheim, Norway.

Oct 24 Karl-Erik Årzén: "Knowledge-based control systems," Reglermöte '90, Linköping, Sweden.

Oct 24 Bernt Nilsson: "An Integrated Environment for Design of Control Systems," Reglermöte '90, Linköping, Sweden.

Oct 24 Jan Eric Larsson: "A Multilevel Flow Model of Steritherm," Reglermöte '90, Linköping, Sweden.

Oct 24 Kjell Gustafsson: "A control theoretic viewpoint of error and convergence control in numerical integration methods," Reglermöte '90, Linköping, Sweden.

Oct 25 Bo Bernhardsson and Per Persson: "An improved moment method for transfer function identification," (Poster), Reglermöte '90, Linköping, Sweden.

Oct 25 Bo Bernhardsson and Anders Rantzer: "Structured stability margin and the finite argument principle," (Poster), Reglermöte '90, Linköping, Sweden.

Oct 25 Tore Hägglund: "A dead-time compensating PI controller," Reglermöte '90, Linköping, Sweden.

Oct 25 Sven Erik Mattsson: "A new method for solution of high index differential-algebraic systems," (Poster), Reglermöte '90, Linköping, Sweden.

Nov 5–8 Karl Johan Åström and Björn Wittenmark: "Adaptive Control," Industrial course, Garmisch Partenkirchen, Germany.

Nov 9 Karl-Erik Årzén: "A knowledge-based control system concept," European Simulation Symposium, Ghent, Belgium.

Nov 9 Jan Eric Larsson: "A Multilevel Flow Model of Steritherm," The 1990 European Simulation Symposium, Ghent, Belgium.

Nov 15 Mats Andersson: "A Kernel for Object-Oriented CACE," the Nordic CACE Symposimum, Lyngby, Denmark.

Nov 15 Sven Erik Mattsson: "CACE in Sweden—A Survey," the Nordic CACE Symposimum, Lyngby, Denmark.

Nov 16 Jan Eric Larsson: "A Multilevel Flow Model of Steritherm," The Nordic CACE Symposium, Technical University of Denmark, Lyngby, Denmark.

Nov 20 Ola Dahl: "Path Following by Sensor Data Combination," STU Seminar, KTH, Stockholm, Sweden.

Nov 22 Lars Nielsen: "Controllability Issues of Robots near Singular Configurations," International Workshop in Adaptive and Nonlinear Control: Issues in Robotics, Grenoble, France.

Nov 28 Karl-Erik Årzén: "Knowledge-based control systems," ABB, Mannheim, Germany.

Nov 29 Karl-Erik Årzén: "Experiences of G2," ABB, Heidelberg, Germany.

Nov 29 Karl Johan Åström: "Adaptive control – From algorithms to products," Plenary talk, IV Congreso Latinamericano de Control Automatico, Puebla, Mexico.

Dec 3 Bo Bernhardsson: "Structure of H-infinity Optimal Controllers – The Golden Section Example," California Institute of Technology, Los Angeles, California.

Dec 4 Karl-Erik Årzén: "A sequential function chart toolbox," G2 Users meeting, Munich, Germany.

Dec 5 Björn Wittenmark: "On the choice of design method in adaptive control," 29th Conference on Decision and Control, Honolulu, Hawaii.

Dec 6 Bo Bernhardsson: "The Predictive First Order Hold Circuit," Honolulu, Hawaii.

1991

Jan 8 Dag Brück: "InterViews User Interface Toolkit," Ellemtel, Stockholm, Sweden.

Jan 9 Dag Brück: "ANSI C++ Committee — Travel report," Ericsson Telecom AB, Stockholm, Sweden.

Jan 30 Karl-Erik Årzén: "Knowledge-based control systems," IT4 conference, Stockholm, Sweden.

Feb 6 Dag Brück: "Building and Object-Oriented Real-Time Kernel," LOOK '91 (Lectures and Object-Oriented Konference), Helsingör, Denmark.

Feb 7 Karl-Erik Årzén: "Knowledge-based control systems," STU, Stockholm, Sweden.

Feb 7 Bernt Nilsson: "SOS/G2 – A Sugar House Simulator implemented in G2," the conference Computer Tools in the Diary Industri, Stockholm, Sweden.

Feb 20 Lars Nielsen: "Some aspects of robotics," Luleå, Sweden.

Feb 26 Kjell Gustafsson: "Controlling numerical integration," Institute for Numerical Analysis, The Technical University of Denmark, Lyngby, Denmark.

March 6 Karl Johan Åström: "Simulation techniques—Tools for specialists and jacks-of-all-trades," SSPA, Gothenburg, Sweden.

March 6 Lars Nielsen: "Efficient Establishment of Correspondences from Affine Shape Indexing," Symposium SSAB (Svenska Sällskapet för Automatiserad Bildanalys) (Swedish Association for Pattern Recognition), Stockholm, Sweden.

March 12 Bernt Nilsson: "Modeling and Simulation of Sugar Crystalization Process," the DUP conference 1991, Stockholm, Sweden.

March 15 Karl Johan Åström: "Intelligent process control," Drexel University, Pittsburgh, Pennsylvania.

March 28 Lars Nielsen: "Detection and Localization based on Area-Invariants," DARPA-ESPRIT workshop on Invariance in Computer Vision, Reykjavik, Iceland.

April 18 Bernt Nilsson: "Modeling and Simulation of Sugar Crystalization Process," the SSA Spring Meeting 1991, Arlöv, Sweden.

April 19 Karl-Erik Årzén: "Process industry applications of knowledge-based systems," KABI Pharmacia, Stockholm, Sweden.

April 23 Jan Eric Larsson: "Model-Based Fault Diagnosis Using MFM," SAIS '91, Uppsala University, Uppsala, Sweden.

April 29 Karl Johan Åström: "Simple adaptive controllers," ETH, Zürich, Switzerland.

April 30 Karl Johan Åström: "Averaging analysis of adaptive systems," ETH, Zürich, Switzerland.

May 2 Karl Johan Åström: "Relay oscillations," ETH, Zürich, Switzerland.

May 6 Karl-Erik Årzén: "Process industry applications of knowledge-based systems," Chalmers, Göteborg, Sweden.

May 14 Karl Johan Åström: "Self-tuning controllers," Monsanto, St Louis, Missouri.

May 16 Karl Johan Åström: "Automatic tuning of controllers: Industrial experiences and future development," Dept of Chemical Engineering, University of Delaware, Newark, Delaware.

May 28 Anders Hansson: "Alternative to Minimum Variance Control," Department of Mathematical Statistics, Lund University, Lund, Sweden.

May 29 Karl-Erik Årzén: "Knowledge-based applications in the process industry," Keynote address, IFAC Workshop on Computer Software Structures Integrating AI/KBS Systems in Process Control, Bergen, Norway.

May 30 Anders Hansson: "Control and Supervision in Sensor-Based Robotics," Robotikdagar, Linköping, Sweden.

May 30 Ola Dahl: "Path Following for a Flexible Joint Robot," Robotikdagar, Linköping, Sweden.

June 3–10 Karl-Erik Årzén: "Knowledge-based control systems," held at the following six places in USA: Esso Petroleum (Toronto, Canada), Bailey Control (Cleveland, Ohio), Monsanto (S:t Louis, Missouri), Du Pont (Newark, Delaware), Univ of Maryland (College Park, Maryland), Honeywell (Phoenix, Arizona).

June 24 Karl Johan Åström: "A response from academia," IFAC Conference on Advances in Control Education, Boston, Massachusetts.

June 24 Kjell Gustafsson: "A Set of Matlab Routines for Control System Analysis and Design," IFAC Conference on Advances in Control Education, Boston, Massachusetts.

June 25 Michael Lundh: "A Package for Laboratory Experiments in Discrete Time Control," IFAC Conference on Advances in Control Education, Boston, Massachusetts.

June 27 Rolf Johansson: "Optimal coordination and control of posture and locomotion," Int. Conf. Artificial Neural Networks, Espoo, Finland.

June 26 Karl Johan Åström: "Education in Automatic Control at Lund Institute of Technology," American Control Conference, Boston, Massachusetts.

June 27 Karl Johan Åström: "An approximate pole placement approach," American Control Conference, Boston, Massachusetts.

June 28 Karl Johan Åström: "Control design for a dynamic vehicle," American Control Conference, Boston, Massachusetts.

H. Travels

Mats Andersson attended the "11th IFAC World Congress" in Tallinn, Estonia, where he presented a paper. In September and October 1990 he spent two months at the Systems Research Center, University of Maryland, working with Prof. Andre Tits on computer aided control engineering. He ended this stay in USA by visiting Steve Murphy at the RPI in Troy, New York, and by running the New York City Marathon. He also attended the Nordic CACE Symposium in Lyngby, Denmark, in November 1990, where he presented a paper.

Karl-Erik Årzén visited General Electric, Schenectady and participated in the "AAAI'90" in Boston, USA, in July 1990. In November he participated in the "European Simulation Symposium" in Ghent, Belgium, and he also visited ABB in Mannheim and Heidelberg, Germany. In December he participated in the "First European G2 Users Meeting" in Munich, Germany.

During spring 1991 Årzén visited EEC JRC Ispra in Italy, and the Technical University Delft in Holland. In May he participated in the "IFAC Workshop on Computer Software Structures Integrating AI/KBS Systems in Process Control", held in Bergen, Norway. As a part of the IT4 project Årzén visited USA and Canada in June together with Claes Rytoft from ABB and Arne Otteblad from STU. The places visited were Esso Petroleum, Bailey Controls, Monsanto, Du Pont, University of Maryland, and Honeywell.

Bo Bernhardsson visited the "11th IFAC world congress" in Tallinn in August. In September he spent a month as a researcher at the automatic control group at Uppsala university, he then also visited the system theory group in Stockholm. In October he participated at the "Reglermöte '90" in Linköping. In December he visited California

Institute of Technology, and participated and presented a paper at the "29th Conference on Decision and Control" on Hawaii.

Dag Brück visited USA in July and November 1990. On both occassions he met with representatives from Microtec Research and the Software Components Group in Santa Clara, CA, to discuss real-time libraries in C++; and he attended the ANSI C++ committee (X3J16) meetings in Seattle, WA, and Palo Alto, CA, respectively. In September he visited Ellemtel, Stockholm, and gave a talk on C++.

In January 1991, Dag Brück visited Ericsson Telecon, Stockholm, and gave a talk on C++. In February, he attended "LOOK '91" (Lectures and Object-Oriented Konference) in Helsingör, Denmark, and gave a seminar. In March he attended the "ANSI C++ committee" (X3J16) meeting in Nashua, NH.

Ola Dahl participated in the symposium "Robotikdagar" in Linköping, May 1991, where he presented a paper.

Kjell Gustafsson participated and presented papers at the "11th IFAC World Congress" in Tallinn, Estonia, USSR, August 1990, and the "1991 Advances in Control Education (ACE) Conference and Exhibit" in Boston, USA, June 1991. He also attended the "1991 American Control Conference" in Boston, USA, June 1991. On February 26, 1991, he visited the Institute for Numerical Analysis at The Technical University of Denmark in Lyngby, and gave a talk on control techniques applied to numerical integration routines.

Anders Hansson attended the "IEEE Global Telecommunications Conference & Exhibition" in San Diego, California, in December 1990, where he together with Thomas Schaub from C-R& D, Landis & Gyr Betriebs AG, Switzerland, presented a paper. Anders Hansson also participated in "Robotikdagar" in Linköping, Sweden, May 30–31, where he together with Lars Nielsen presented a paper.

Per Hagander participated in the following conferences: the "5th European Congress on Biotechnology", Copenhagen, in July 1990,

where he made a poster presentation; in the "11th IFAC World Congress", Tallinn, in August, where he presented a paper; and in the "IEEE CDC conference", Honolulu, in December. In April 1991 he visited UMIST, UK, in order to arrange for a possible Erasmus student exchange.

Tore Hägglund participated and presented a paper at the "11th IFAC World Congress" in Tallinn in August 1990. In October 1990, he visited the Norwegian Institute of Technology in Trondheim and Linköping University. He acted as an external examinar at three PhD dissertations, one in Gothenburg in December 1990, one in Luleå in April 1991, and one at DTH in Lyngby, Denmark, in May 1991.

Ulf Holmberg attended the "IAWPRC conference" in Kyoto, Japan, in July 1990 and presented a paper.

Rolf Johansson participated in and presented papers at the conferences "Xth International Symposium of the Society for Postural and Gait Research", Munich, Germany, in September, 1990; "Reglermöte '90", Linkoping, Sweden, in October; and "Int. Conf. on Artificial Neural Networks", Espoo, Finland, in June 1991.

Rolf Johansson visited the Automatic Control and Systems Analysis Group, Uppsala University on 7 December 1990 to participate in the examination committee for the doctoral dissertation of Mr. Torbjörn Wigren, Uppsala. He also acted as an external examiner of the licenciate thesis of Ms. Ke Wang Chen, Division of Automatic Control, Linköping University, 31 May 1991.

Jan Eric Larsson participated in the following conferences during the fall 1990: the "9th European Conference on Artifical Intelligence" in Stockholm; the "11th IFAC World Conference" in Tallinn, Estonia; "Reglermöte '90" in Linköping; the "European Simulation Symposium" in Ghent, Belgium; and the "Nordic CACE Symposium" in Lyngby, Denmark.

In January, February and April 1991 he participated in three different Discos planning sessions. The first one was held in Lyngby, Denmark, the second one in Varese, Italy, and the third one in Delft, Holland. In April he also participated in SAIS '91 in Uppsala, Sweden.

Michael Lundh visited the "11th IFAC World Congress" in Tallinn in August. He also visited the conferences "Advances in Control Education" and the "American Control Conference", both held in Boston, USA, in June 1991.

Sven Erik Mattsson participated in the "11th IFAC World Congress" in Tallinn, Estonia, in August 1990. In October he attended the "Reglermöte '90" in Linköping, Sweden, where he presented a poster. In November he attended the "Nordic CACE Symposium" in Lyngby, Denmark, where he presented a paper.

Mats Lilja participated in the "11th IFAC World Conference", Tallinn, Estonia, August 13–17, 1990.

Lars Nielsen is a member of the Board of SSAB (Svenska Sällskapet för Automatiserad Bildanalys) (Swedish Association for Pattern Recognition), The European Laboratory Network in adaptive and non-linear control applied to robotics, and an initiating group for SNART (Svenska Nationella Arbetsgruppen för RealTid (Swedish National Group for Real-Time)). These three involvments have all included travels to meetings.

He participated and presented contributions in the following conferences: the "2nd International Workshop on Advances in Robot Kinematics", Linz, Austria, in September; the "International Workshop in Adaptive and Nonlinear Control: Issues in Robotics", Grenoble, France, in November; "Symposium SSAB" (Svenska Sällskapet för Automatiserad Bildanalys) (Swedish Association for Pattern Recognition) Stockholm, Sweden, in March; "DARPA-ESPRIT workshop on Invariance in Computer Vision", Reykjavik, Iceland, in March; Symposium "Robotikdagar", Linköping, Sweden, in May.

Bernt Nilsson presented a poster at the "DUP conference" in Stockholm in March 1990, and in April he visited the Sugar Company in Svedala and in Hasslarp. Bernt Nilsson participated in "Reglermöte '90", Linköping, Sweden. In February and March 1991 he visited STU in Stockholm twice for presentation of the DUP project at the department. Bernt Nilsson was invited to the SSA spring meeting in April 1991 to present the DUP project.

Lars Rundqwist participated in the "11th IFAC World Congress" in Tallinn, Estonia, USSR, August 1990, where he presented a paper.

Björn Wittenmark participated and made presentations at the conferences "11th IFAC World Congress" in Tallinn, Estonia, and "29th Conference on Decision and Control" in Honolulu, Hawaii. Further he lectured at an industrial course in Adaptive Control in Garmisch Partenkirchen, Germany.