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Activity Report

Automatic Control

1991–1992

Department of Automatic Control
Lund Institute of Technology

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Activity Report

Automatic Control

1991–1992

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Contents

1. Introduction

This report covers the activities at the Department of Automatic Control at Lund Institute of Technology (LTH) during the period 1 July 1991 – 30 June 1992, which is the academic year 1991/92. The budget for the year was 14.5 MSEK. This figure does not include rent for offices and laboratories.

During this period Ulf Holmberg, Michael Lundh, Kjell Gustafsson, Per Persson, and Ola Dahl completed their PhD theses. This brings the total number of PhDs graduating from our department to 38. Further Anders Hansson, Per-Olof Källén, and Klas Nilsson presented their Licentiate theses. Twentyseven students completed their MSc degree at the department. 15 journal papers or book chapters and 41 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 228 groups of experiments. Three 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.

Lars Nielsen left the department to become professor in Vehicular Systems at Linköping University. He is the ninth person from the department that has become a professor in Sweden.

It has been possible to continue to upgrade the computing facilities at the department thanks to generous contributions from the Swedish Council for Planning and Coordination of Research (FRN) and Apple Computer AB.

The report is organized as follows. Economics and facilities are presented in Chapter 2. The educational activity is described in Chap-

ter 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 adaptive control is given in Chapter 6. Detailed informations about awards, theses, publications, seminars and lectures are given in the Appendices.

Acknowledgement

We want to thank our sponsors, the Swedish National Board for Industrial and Technical Development (NUTEK), the Swedish Research Council for Engineering Sciences (TFR), the Swedish Council for Planning and Coordination of Research (FRN), the Swedish Medical Research Council (MFR), ABB, Apple Computer AB, and Sydkraft for their support to our projects.

2. Economics and Facilities

Economics

The income for the academic year 1991/92 was 14.5 MSEK. This does not include rent for offices and laboratories, which is paid from other accounts. We had a large grant of 1 MSEK for upgrading of our computer system. The remaining income is distributed as follows: 62% from the university, 21% from government agencies, 9% directly from industry, and 8% from software contracts and small projects.

The operating costs are: salaries 9.8 MSEK, university overhead 0.5 MSEK, and operating costs 4.2 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 nine scientific visitors during the year. Details of the personnel are given in Appendix A.

Facilities

Our computer facilities were described in detail in the annual report of last year, TFRT-4019. Through a grant from the Swedish Council for Planning and Coordination of Research (FRN) and a donation from Apple Computer AB it has been possible to further build up our computer capacity. The following computers are now available for research and education:

1 Sun4/690, 2.5GB disk

2 SparcStation2 with color

28 SparcStation

16 Sun3

14 IBM PC/AT

1 PC 486

8 Macintosh computers

3 VME based control computers MC68030/68040

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)	292
Reglerteknik AK–M (Automatic control, basic course)	103
Processreglering (K) (Automatic process control)	103
Digital Reglering (FED) (Computer-controlled systems)	89
Datorimplementering av reglersystem (FED) (Computer implementation of control systems)	40
Processidentifiering (FED) (Process identification)	36
Adaptiv reglering (FED) (Adaptive control)	25

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

summary 688 students have graduated from courses at the department during the academic year 1991/92.

The control laboratory has been used extensively during the year. Simple fixed experiments are done in the basic courses. In the courses on adaptive control and system identification there are also open ended experiments. In the basic courses we can have up to eight parallel groups and in the elective courses we have four parallel experiments. There were 228 groups of students that made laborations at the department. Over the year the laboratory is used about 84% of the time. For scheduling reasons there are also many experiments in the evenings.

Master Theses

Twentyseven students completed their master theses during the year. A list is given in Appendix D.

The theses concerned the following application areas: Adaptive control (5), Biomedical engineering (2), Econometrics (1), Fuzzy control (1), Man-machine interaction (1), Power systems (4), Process control (4), Robotics and servomechanisms (1), Sequential control (2).

Doctorate Program

Five PhD theses were completed during the period: Holmberg (1991), Lundh (1992), Gustafsson (1992), Persson (1992), and Dahl (1992). Further, three Licentiate theses were presented: Hansson (1991), Källén (1992), and Nilsson (1992). The abstracts of these are given in Chapter 5. This brings the total number of PhDs graduating from our department to 38. Three new PhD students (Anders Nilsson, Karl Henrik Johansson and Johan Nilsson) were admitted to the department.

The following PhD courses have been given:

- Linear systems (P. Hagander) 10 p
- Synthesis (P. Hagander, K. J. Åström) 8 p
- Model-based diagnosis (K. E. Årzén) 2 p

During the year the department has taken the initiative to create a graduate program in Systems and Applied Mathematics at Lund Institute of Technology. The program is a cooperation between the departments of Mathematics, Mathematical statistics, Automatic control, Telecommunication theory, Communication 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. The first result is a compiled list and a coordination of courses given by the different departments. A second result is the development of a new course "Simulation of deterministic and stochastic systems." This course is developed and organized by several of the departments within the program and is scheduled for 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

Our research on adaptive control has been very successful and several industrial products based on our ideas are now available. There are two key issues in making useful adaptive systems. One is to combine robust and adaptive control, the other is to make adaptive systems easy to use.

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 is under investigation. 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.

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. Future research will be 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 and Per Hagander

This is a project that in its present form covers robust control rather than adaptive control. The first step is to define control problems and to construct design methods for processes with uncertainties. This is described in Section 4.2. In a second step the adaptive versions of the methods will be considered.

Automatic Tuning

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

At the department we have developed methods for automatic tuning of PID controllers. The key idea is to exploit information about the

process dynamics from experiments with 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. The results are given in the PhD thesis by Ulf Holmberg. Work on improved tuning rules for PID controllers is also in progress. In his PhD thesis, Per Persson proposes tuning rules, which are based on the idea of dominant pole design. This research has shown that well-tuned PID controllers give surprisingly good behavior.

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 initialize adaptive controllers. 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. Interesting results in this area are given in the PhD thesis by Michael Lundh. It is shown how simple experiments can be used to initialize self-tuning controllers.

Autonomous Control

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

Work on autonomous control has been going on since 1985, previously under the name Expert Control. The goal of the work is to extend the functionality of conventional controllers to also include intelligent tuning, adaptation, performance assessment, and loop diagnosis. The implementation is based on using a real-time expert system that supervises numerical control, identification, and monitoring algorithms. The work during the last year has focused on PID design methods, oscillation detection and diagnosis, and G2 implementation.

Control Theory

Linear System Theory

Researchers: Per Hagander and Bo Bernhardsson

The interest in linear system theory has recently been renewed. This has taken several different forms and has resulted in several papers and conference contributions and in one PhD-thesis to be presented in the fall 1992. The activity is closely connected to the work on robust adaptive control. Triggered by two graduate courses in H_∞-theory given by professors Michael Green (1990) and Tamer Basar (1991) we started with the parametrization and behavior of H_∞-*optimal* controllers. Our interest in limitations of the H_∞-theory is now focused on the study of so called *min-mix control* problems. In these optimal control problems deterministic disturbances model worst case situations and stochastic signals 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

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.

Most critical processes are equipped with supervision. Often an alarm is given when a signal crosses a certain alarm level. Then an operator, depending on the situation, either initiates emergency shutdown or a temporary change of the operational conditions. This temporary

change could be to choose a new reference value in order to avoid that the controlled signal continues to increase and thus preventing an exceedance of a higher more dangerous level. This change of reference value is mostly done in an ad hoc fashion.

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.

Computer Aided Control Engineering

Modeling and Simulation Environments

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

The CACE project has during the last five years focused on modeling and simulation. A new object-oriented modeling language called Omola has been developed. 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 behavior descriptions should be declarative and equation based which implies that a model can be used for various purposes in different applications. Omola permits a wide variety of formalisms to describe behavior.

An environment called OmSim to support development and simulation of continuous time models (differential-algebraic equations and

difference equations) with discrete event elements is under development. The aim is to bring OmSim to a stage where it can be used by external groups in case studies. OmSim is also meant to serve as a work-bench and a framework for further research as well as a base for companies that would like to develop commercial products of general-purpose or special-purpose types.

The development of OmSim has during the last year included research on architectural issues of simulators and development of methods and algorithms for analyzing and transforming the Omola models to a form suitable for simulation.

Control of Error and Convergence in ODE Solvers

Researchers: Kjell Gustafsson in cooperation with Gustaf Söderlind (Department of Computer Science)

A robust implementation of a numerical integration method involves the design of strategies and algorithms to supervise and run the integration in an accurate and efficient way. This task is far from simple. An advanced integration method includes parameters and variables that should be adjusted during the execution. In addition, the algorithm should be able to automatically handle the initialization, restart after possible failures, etc.

We have approached the design of the supervisory algorithms using analogies from automatic control. The work has lead to new algorithms for stepsize selection in explicit and implicit Runge-Kutta methods, as well as new strategies for the convergence control of the equation solver in implicit Runge-Kutta methods. The new algorithms are straightforward to implement and lead to improved efficiency and accuracy.

Applications

The major application projects are knowledge-based control and diagnosis and robotics.

Knowledge-Based Control and Diagnosis

Researchers: Karl-Erik Årzén and Jan Eric Larsson

The department has been a partner of the IT4 project "Knowledge-based real-time control systems" together with ABB. The aim of the project was to specify and verify a system architecture that integrates knowledge-based techniques with conventional distributed control systems. The concept is based on a 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 has been used as a test example.

In order to visualize the concept a demonstrator has been developed in G2. The demonstrator 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, alarm analysis based on functional MFM models, fault tree based off-line alarm analysis, production scheduling, and a product following system.

The functional modeling formalism Multi-level Flow Models (MFM) developed by Morten Lind at DTH is used as a base for diagnosis schemes. This is the thesis subject of Jan Eric Larsson. He has developed general methods for measurement validation, alarm analysis, and fault diagnosis based on MFM models. The methods have been implemented as a toolbox in G2.

Robotics

Researchers: Klas Nilsson, Ola Dahl, and Lars Nielsen

A laboratory for robotics and sensory control has been established. The experimental work is centered around an ABB Irb-6 robot. Hardware interfaces have been developed to create an open system suitable for control experiments. One experimental setup is a separate ABB Irb-6 DC servo-motor. 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 the 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 results are presented in the PhD thesis by Ola Dahl.

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. One aim is to provide a layer between a supervisory sequence control layer and the basic control level. The results are presented in the licentiate thesis by Klas Nilsson.

Other projects, involving also other researchers, 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.

Fast Digital Control

Researchers: Karl Johan Åström

The goal of this project is to develop digital control algorithms that can operate at high sampling rates. This will significantly expand the application areas for digital control. The experimental platform is a Macintosh computer with a DSP board with the TMS320 processor. We have focused on adaptive algorithms. The problem of adaptive prefiltering and postfiltering have been investigated. Such filters have been implemented using dual rate systems. It has been shown that measurement noise and excitation of high frequency modes can be reduced significantly using this approach. Two adaptive control algorithms that can run at several kHz have also been developed and tested in typical servo applications. See the internal report Jagannathan and Åström (1992) and the Master thesis Olsson and Svensson (1992). The system has also been used for projects in our course on Adaptive control, see the report Åström (1992). For convenient experimentation an adaptive algorithm has also been implemented as a virtual instrument in LabView.

Power Systems

Researchers: Lars Rundqwist, Ulf Holmberg, and 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.

5. Dissertations

Five PhD dissertations and three Lic Tech dissertations were defended during the year. The abstracts are presented below.

Relay Feedback of Simple Systems

Ulf Holmberg
PhD dissertation, 4 October 1991

In the fifties there was much work on relay systems. Lately, there has been a renewed interest in systems with relay feedback. One of the reasons is the use of relay feedback for automatic tuning of PID controllers. Another reason is the renewed interest in the theory of dynamic systems and chaotic behaviour. However, systems with relay feedback may have very complex behaviour that is not fully understood. The goal of this thesis is to contribute to the understanding of such systems. This is done by a detailed analysis of first and second order systems with time delays. The main contribution is a thorough investigation of first order systems with time delays and a direct term. The direct term and the time delay makes this problem far from trivial. Different types of limit cycles are observed and classified. Their convergence regions are also specified and it is shown that the limit cycle can be reached already after one switch. The analysis of second order systems with relay feedback is not complete but aim to give an understanding of the convergence mechanisms. It is shown that the convergence is very fast for systems with real eigenvalues that are widely spread. These results explain the fast convergence of the relay auto-tuners that have been observed in practice. It is also shown how relay feedback can be used as excitation for parameter estimation. This idea is applied to the problem of determining dynamics of a biological reactor. The estimator has been simulated and tested in a full scale experiment at Malmö Sewage Works.

Minimum Risk Control

Anders Hansson
Lic Tech dissertation, 29 November 1991

A new optimal stochastic control problem is posed. The criterion is to minimize the probability for a largest value of a signal to be above a level given a certain reference value. It is shown that this control problem is closely related both to the problem of minimizing the variance of the signal—minimum variance control—and to the problem of minimizing the so called upcrossing probability. It is made plausible that the upcrossing probability is a better approximating criterion to minimize than the minimum variance criterion. The problem of minimizing the upcrossing probability can be thought of as finding optimal weighting-matrices in an LQG-problem. The new controller is compared with the minimum variance controller for a first order process. It is seen that the new controller causes a lower upcrossing intensity and a smaller probability for the largest value of the controlled signal to be above the critical level. The improvement in the example is up to about 10%. This makes it possible to choose the reference value closer to the critical level when using the minimum risk controller, than when using the minimum variance controller. Further it is seen that the control signal is more well-behaved. The only drawback of the new controller is the larger computational burden.

Robust Adaptive Control

Michael Lundh
PhD dissertation, 24 January 1992

This thesis deals with two problems in robust and adaptive control. First a method for robust control system design is presented. A constrained convex optimization problem is used to find a controller that guarantees robust performance for an uncertain process where the

uncertainty is described as a combination of structured and unstructured uncertainties. Adaptive control is an alternative way to deal with uncertain processes. However, adaptive controllers may be difficult to commission. A method for automatic initialization of an adaptive controller is presented. The method uses information from an experiment with relay feedback to initialize a robust adaptive controller.

Control of Error and Convergence in ODE Solvers

Kjell Gustafsson
PhD dissertation, 22 May 1992

Feedback is a general principle that can be used in many different contexts. In this thesis it is applied to numerical integration of ordinary differential equations. An advanced integration method includes parameters and variables that should be adjusted during the execution. In addition, the integration method should be able to automatically handle situations such as: initialization, restart after failures, etc. In this thesis we regard the algorithms for parameter adjustment and supervision as a controller. The controller measures different variables that tell the current status of the integration, and based on this information it decides how to continue. The design of the controller is vital in order to accurately and efficiently solve a large class of ordinary differential equations.

The application of feedback control may appear farfetched, but numerical integration methods are in fact dynamical systems. This is often overlooked in traditional numerical analysis. We derive dynamic models that describe the behavior of the integration method as well as the standard control algorithms in use today. Using these models it is possible to analyze properties of current algorithms, and also explain some generally observed misbehaviors. Further, we use the

acquired insight to derive new and improved control algorithms, both for explicit and implicit Runge-Kutta methods.

In the explicit case, the new controller gives good overall performance. In particular it overcomes the problem with an oscillating stepsize sequence that is often experienced when the stepsize is restricted by numerical stability. The controller for implicit methods is designed so that it tracks changes in the differential equation better than current algorithms. In addition, it includes a new strategy for the equation solver, which allows the stepsize to vary more freely. This leads to smoother error control without excessive operations on the iteration matrix.

Frequency Domain Adaptive Control

Per-Olof Källén
Lic Tech dissertation, 26 May 1992

Adaptive controllers are normally based on the assumption that the process can be described by a linear model of known order. Also they rely on the certainty equivalence principle, i.e. the model uncertainty is not taken into account in the controller design. In practice process modeling is always approximate. This raises the question of how robust adaptive controllers are in view of uncertainties and under modeling. In the literature it has been argued that both the estimation and the controller design must be made robust to uncertainties and under modeling in order to obtain a robust adaptive controller. This thesis is a step in that direction, not by relying on uncertainty measures but instead by not basing the scheme on a rational transfer function model of the process. Instead both the process modeling and the controller design are formulated in the frequency domain. The process is in the scheme represented by a set of points on the Nyquist curve of the process. The actual process order is then irrelevant from a modeling point of view. The controller design is formulated as an approximation problem in the frequency domain. In this the closed

loop response to command signals is fitted to a desired response supplied by the user. The explicit solution to a least squares problem gives the controller parameters. The necessary process knowledge is obtained from a bank of low order estimators. By using a bank of band pass filters the process estimation is decoupled in the frequency domain. Low order controllers can in the scheme be used to control high order plants.

Application Oriented Programming and Control of Industrial Robots

Klas Nilsson
Lic Tech dissertation, 1 June 1992

Efficient use of industrial robots requires a strong interplay between user level commands, a good but not perfect world model, the motion control system, and external signals. It should also be possible for an experienced application engineer to tailor the motion control to a specific application in a convenient way, instead of deficient utilization of the device or tricky user programming which is often the case today. A software architecture has been designed based on a problem oriented view of industrial applications and considering typical hardware and software constraints. An experimental platform, built around commercially available robots, has been developed to verify the proposed solutions.

The top layers of the architecture support improved integration of off-line programming with interactive teach-in programming. A central part of the architecture is an intermediate software layer on top of the general purpose motion control system, allowing the experienced user to introduce application specific motion primitives. Flexibility during system configuration combined with computing efficiency and performance at run-time is of major importance. The software solutions include a concept of motion pipelining allowing sensor based motions to be partly computed in advance, and a concept of method

passing which is used to pass application specific parameters to the general purpose parts of the system. Those methods are implemented as compiled relocatable procedures that can be passed between different processors in the control system, and executed in the context of the application independent motion control software.

Towards Autonomous PID Control

Per Persson
PhD dissertation, 2 June 1992

The thesis consists of two parts. The first part describes an expert system interface, named `(ihs)`, for the interactive data analysis and system identification program Idpac. The interface works as an intelligent help system. The system is completely non-invasive and uses the previous command history to understand what the user is doing and gives help according to this. This way of monitoring the user's activities is called the *command spy strategy. Scripts* are used for representing procedural knowledge, and production rules for diagnostic knowledge. The system has been implemented and a knowledge database handling system identification with the maximum-likelihood method has been developed. An example run with the system is included.

The second part describes new methods to tune PID controllers. The methods are based on placement of the dominant poles of the system. Different design criteria are discussed and compared. Design methods based on maximizing the integrated error for a load disturbance and specification of a maximal value of the sensitivity function are recommended.

Path Constrained Robot Control

Ola Dahl
PhD dissertation, 3 June 1992

Fast motion along a predefined path is important in many robot applications, and requires utilization of the maximum allowable torque range. If the torque is at the limit, there is no margin to cope with disturbances or modeling errors, which may result in deviation from the path. A path velocity controller outside the ordinary robot controller modifies a nominal velocity profile, which is specified in advance, e.g. by minimum time optimization or by a robot operator/programmer. Existing minimum time optimization methods for rigid robots give the nominal velocity profile and also insight into the constraints. Flexible joint robots are treated by a polynomial approximation of the robot velocity along the path, and the specific approximation is chosen such that the boundary conditions on zero velocity and nonzero torque are satisfied.

The path velocity controller modifies a scalar path parameter, giving computational efficiency and coordination of joint motions. A basic algorithm limits the acceleration, which may be inadmissible due to modeling errors. An extended algorithm handles the added problem of inadmissible velocity. The path velocity controller is verified by experiments on an industrial robot. The experiments are done such that it is possible to separate the performance of the path velocity controller from the performance of the robot controller. Path deviation and torque utilization are discussed and evaluated. The experiments show that the path velocity controller can adjust a nominal minimum time velocity profile, such that the result is good path following and good utilization of the available torque range.

The use of path velocity control makes it possible to have a nominal velocity profile which exceeds the robot capability. This is not possible if the reference trajectory is fixed. The experimental results also show how path velocity control makes it possible to use minimum time optimization in a nonideal situation.

6. Looking Back

Research is a long term commitment. In this annual report we illustrate this by looking at our research in adaptive control. Adaptive control has been a major research area at the department since about 1966, i.e. for about 25 years.

Adaptive control was a "hot" subject in the mid 1950s. The research and applications were, however, hampered by hardware and computational limitations. System identification was developed into a major research field in the mid 1960s. This together with the development of digital computers made it possible to revitalize the research in adaptive control. The work at the department started with a literature search and investigations of published methods. The work was headed by Professor Karl Johan Åström and graduate work was started in this area by Björn Wittenmark, Ulf Borisson, Johan Wieslander, and Lennart Ljung. Ideas for adaptive control based on real-time estimation were presented at a symposium in Prague in 1970. The research by Åström and Wittenmark lead to the development of self-tuning regulators. The first self-tuning regulators were based on a combination of least squares estimation and minimum variance control. Simulations showed that this was a very rewarding approach. The closed loop system obtained with self-tuning controllers were, however, complicated. Insights gained from simulations inspired theoretical analysis that lead to a development of a theory for self-tuning regulators. The first results were presented at the IFAC World Congress in Paris 1972 and published in Automatica a year later.

In parallel with the theoretical development of the self-tuning regulators we approached Billerud AB in Grums to be able to test the ideas on real industrial processes. Through financial support from STU and the enthusiasm from the plant management a project for moisture content control of a paper machine started in the spring of

1972. The first successful experiments on the paper machine PM6 at Gruvön were made in the summer that year by Björn Wittenmark and Ulf Borisson. This feasibility study was followed by new applications. Control of an ore crusher at LKAB in Kiruna was done from a computer in Lund via modem and the public telephone net in November 1972. This project was done in cooperation with a former MSc student from the department, Rolf Syding.

Together with the ship yard Kockums in Malmö a development project on adaptive autopilots was started in the fall of 1973. Karl Johan Åström and Claes Källström together with two former MSc students Johannes Ericsson and Leif Steen developed a prototype for an adaptive autopilot. The autopilot was tested on a large tanker on trips from the Persian Gulf starting in October 1973. The project is described in the thesis by Källström (1979). A commercial autopilot based on the ideas were developed by Kockumation AB in Malmö. The product was announced in 1979 and is still being marketed. Källström started to work at SSPA in Gothenburg after his dissertation. There he developed an adaptive system for roll damping in ships called ROLLNIX. An adaptive steering function was added to this in a Master thesis project by Kalle Theorén, who later joined SSPA.

The initial work and the successful applications of adaptive control lead to an extensive theoretical development in the 1970s. Basic work on the theoretical and applied aspects were presented in the theses by Wittenmark (1973), Ljung (1974), and Borisson (1975). The self-tuning concept was extended into work on dual control, Sternby (1977), and self-tuning prediction, Holst (1977). A first stability proof for adaptive controllers was presented in Egardt (1978). A first attempt to solve the adaptive start-up problem was done in Lenells (1982). Convergence and stability were extended to multivariable adaptive controllers in Johansson (1983). A counter example by Rohrs from MIT caused much discussions in the adaptive research community. Using averaging techniques it was possible for us to analyze systems with unmodeled dynamics. This was an important step towards the understanding of stability and robustness of adaptive controllers. Directional forgetting methods and adaptation at jumps in

the parameters of the process were treated in Hägglund (1983). The problem of specifying necessary and sufficient knowledge for adaptive stabilization was solved in Mårtensson (1986). Initialization of self-tuning regulators is discussed in Lundh (1991).

The ideas of self-tuning regulators were transferred to industry, partly through joint projects. The academic algorithms were transferred into practically usable algorithms and the first general purpose adaptive toolbox, Novatune, was put on the market by Asea, now ABB, in 1982. This toolbox is now available within the ABB Master system for process control. Gunnar Bengtsson, a PhD student from the department, lead the development at ABB together with Rolf Syding. Later Bo Egardt, also a PhD student from the department, took over the development at ABB. A new company, First Control, was founded by Gunnar Bengtsson and Rolf Syding. They introduced a new generation of adaptive toolboxes in 1986 and are today producing the fastest commercial adaptive controllers.

A special purpose adaptive controller has been developed by Gambro AB in Lund. The project was headed by the former PhD student Jan Sternby. The adaptive control loop is used for fluid control in dialysis machines. Because of the large number of different dialyzers available on the market, the dialysis machine must be able to handle a wide span in process gain and other process characteristics including the patients. The system has performed well, and is probably one of the most widely used adaptive controllers in the world today.

In connection with the applications of adaptive control we found that there were difficulties when transferring the theories and knowledge to industry. The jump from simple process controllers to advanced adaptive controllers was at many occasions too big. Two new lines of research were then started up at the department: auto-tuning and expert systems. These developments are worth a story of their own that will be told in forthcoming issues of our annual reports.

The research on adaptive control has had a significant impact on the research community. Many other research groups have taken up the problems. Adaptive control has also been a large area at many con-

ferences. We have actively been pursuing this both within IFAC and IEEE. For instance, K. J. Åström was invited to give a plenary lecture on the field for the 8th World Congress of IFAC in Kyoto in 1981. An expanded version of this lecture, "Theory and Applications of Adaptive Control" Automatica, **19** (1983) pp 471–486, received the best paper award at the IFAC World Congress in Budapest 1984. In 1986 we organized an IFAC workshop on Adaptive Systems in Control and Signal Processing in Lund. This attracted 188 visitors from 24 countries. The workshop is now expanded to a symposium, which is held triannually in different parts of the world. The paper "Adaptive Feedback Control" by Karl Johan Åström, which appeared in Proceedings of IEEE in 1987, was awarded the Donald G. Fink Prize Paper Award for IEEE in 1989. In 1991 Björn Wittenmark was elected an IEEE Fellow with the citation: "For contributions to adaptive control and to the development of self-tuning regulators".

To spread the results of the research Åström and Wittenmark have written the book "Adaptive Control," which is used at many universities, including Lund, where a course on adaptive control at the masters level is given. Courses on adaptive control for industrial engineers have been given in Sweden and abroad on many occasions.

Altogether there have been 12 PhD theses and 55 MSc theses related to adaptive control at the department. It has been important to be able to pursue the research on adaptive control over a longer period of time. It is rewarding to see that our work in the area of adaptive control has a significant influence on the research in the field and that it has had a great impact on the industry. New controllers based on our research are now on the market, and the demand from the users is increasing. Our work on adaptive control has mainly been sponsored by the Swedish Board of Technical Development (STU), now NUTEK. Without this long term support it would have been impossible to carry out the research at a reasonable level and transfer the technology from university to industry. This support and encouragement is gratefully acknowledged.

A. Personnel and Visitors

During the year the following persons have been employed at the department. The list shows the status of June 1992 if nothing else is mentioned.

Professorer (Professors)

Karl Johan Åström
Björn Wittenmark

Högskolelektorer (Associate professors)

Per Hagander
Tore Hägglund
Rolf Johansson
Lars Nielsen (until January 1992)
Ola Dahl

Forskarassistent (Research associate)

Sven Erik Mattsson

Forskningsingenjörer (Research engineers)

Leif Andersson
Anders Blomdell
Rolf Braun
Kjell Gustafsson
Ulf Holmberg (until 17 April 1992)
Michael Lundh (until February 1992)
Per Persson
Tomas Schönthal

Forskningsassistenter (Research assistants)

Karl-Erik Årzén (from March part time at ABB)
Dag Brück

Doktorandtjänster (Teaching assistants)

Mats Andersson
Bo Bernhardsson
Anders Hansson
Ulf Jönsson
Per-Olof Källén
Jan Eric Larsson
Jörgen Malmborg (from Sept 1991)
Anders Nilsson (from Oct 1991)
Bernt Nilsson
Klas Nilsson
Henrik Olsson

Institutionssekreterare (Secretaries)

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

Assistent (Technical drawings)

Britt-Marie Mårtensson

Arvode (Temporary appointments)

Karl Henrik Johansson (from June 1992)
Mats Lilja (until Sept 1991)
Johan Nilsson (from June 1992)

Visiting Scientists

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

Mr Patrick Saurrat
Laboratoire d'Automatique de Grenoble
ENSIEG, Grenoble, France
(8 April – 13 August 1991)

Ms Maria Jesus de La Fuente
Dpto de Ingenieria de Sistemas y Automática
Universidad de Valladolid, Valladolid, Spain
(10 September – 8 November 1991)

Mr Per Christer Lund
Institutt for Kjemiteknikk, NTH
Trondheim, Norway
(16 September – 18 December 1991)

Professor Carlos Canudas de Wit
Laboratoire d'Automatique de Grenoble
ENSIEG, Grenoble, France
(24 September – 11 October 1991)

Dr Lino Guzella
Automatic Control Lab, ETH
Zurich, Switzerland
(21–25 October 1991)

Mr Martin Balters
Department of Automatic Control, ETH
Zurich, Switzerland
(18 November 1991 – 27 March 1992)

Dr K. Jagannathan
Singapore Institute of Technology, Singapore
(7 January – 27 March 1992)

Dr Assen Todorov
Technical University, Department of Automation
Sofia, Bulgaria
(18–22 May 1992)

Dr Stephen Murphy
Rensselaer Polytechnic Institute
Troy, New York
(19–21 May 1992)

Special Visits

On March 18, 1992, a group of students from the Netherlands visited the department on their study tour to Scandinavia, called "Viking Tour 1992." The group consisted of 2 mathematicians and 24 mathematical students and the tour was organized by the Mathematical Students Society Abacus.

B. Awards and External Activities

Awards

Bo Andersson and **Joachim Grebe** received the Sydkraft Research Foundation Award for their Master thesis "Computer Control of a Heating Plant."

Bo Bernhardsson received a scholarship from the Sweden–America Foundation to spend a year as research associate at the Institute for Mathematics and its Applications at University of Minnesota.

Kjell Gustafsson has received scholarships from the Hans Werthén fund and the Claes Adelskölds fund to spend a year as post doctoral fellow at Stanford University.

Anders Hansson received the Nils Hörjel scholarship.

Anders Hansson and **Michael Lundh** received the Saab-Scania Scholarship in May 1992.

Anders Nilsson received the ABB award for the best Master thesis 1991 at Lund Institute of Technology for his thesis "Qualitative Model-Based Diagnosis—MIDAS in G2."

External Activities

Member of Advisory Committees and Working Groups

Karl Johan Åström. Member of Evaluation group of the Research Activities in Electrical Engineering at the ETH, Zurich. Member of the Scientific Policy Advisory Committee (SPAC) for evaluation of Mathematics and Natural Sciences at Uppsala University. Member of Research Advisory Council, Institute for Systems Research,

University of Maryland. Member Research Advisory Council, Laboratory for Information and Decision Systems, MIT. Member of the IEEE Technical Field Awards Committee. Member of the Swedish Research Council for Engineering Sciences (TFR). Chairman of the Awards Committe for the Quazza Medal.

Dag Brück. Member of ANSI X3J16, C++ standardization committee. Head of Swedish delegation of ISO/IEC JTC1/SC22 WG21, Programming Language C++, the ISO standardization committee for C++.

Björn Wittenmark. Member of advisory group on food industry of the NUTEK program DUP.

Board Member

Karl Johan Åström. Vice President of the Royal Swedish Academy of Engineering Sciences (IVA). Member of the Board of Swedish Institute of Computer Science (SICS).

Björn Wittenmark. Member of Boards of Governors for IEEE Control System Society.

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-Erik Årzén. Member of IPC for IFAC Symposium on On-line Fault Detection and Supervision in the Chemical Process Industries, University of Delaware, Newark, April 1992.

Dag Brück. Member of program committee, USENIX C++ Conference, August 1992.

Opponent and Member of Examination Committee

Karl-Erik Årzén. Member of examination committee of the PhD thesis by Thomas Petti, University of Delaware, April 1992.

Karl Johan Åström. Member of examination committee of the thesis by Anders Rantzer, KTH, Dec 1991. External examiner of the thesis by Weng Khuen, Singapore, January 1992. Member of examination committee of the thesis by Georg Kristian Brustad, Norweigan Institute of Technology, March 1992.

Per Hagander. Member of examination committee of the thesis by Ulf Ryde-Pettersson, Lund University, September 1991.

Tore Hägglund. Member of examination committee of the thesis by Ulf Holmberg, Lund Institute of Technology, October 1991.

Rolf Johansson. External examiner of the thesis by Thor Inge Fossen, Norwegian Institute of Technology, September 1991.

Sven Erik Mattsson. Member of examination committee of the thesis by Peter Nagy, Linköping University, June 1992.

Björn Wittenmark. Member of examination committee of the thesis by Krister Forsman, Linköping University, December 1991.

C. External Publications

Papers

Åström, Karl Johan: "Adaptive control." In Antoulas, Ed., *Mathematical System Theory*, pp. 437–450. Springer-Verlag, 1991.

Åström, Karl Johan, C. C. Hang, P. Persson, and W. K. Ho: "Towards intelligent PID control." *Automatica*, **28:1**, pp. 1–9, 1992.

Canudas de Wit, C., N. Fixot, and Karl Johan Åström: "Trajectory tracking in robot manipulators via nonlinear estimated state feedback." *IEEE Trans. Robotics and Automation*, **8**, February, pp. 138–144, February 1992.

Gustafsson, Kjell: "Control theoretic techniques for stepsize selection in explicit Runge-Kutta methods." *ACM Transactions on Mathematical Software*, **17:4**, pp. 533–554, December 1991.

Hägglund, Tore: "A predictive PI controller for processes with long dead times." *IEEE Control Systems Magazine*, **12:1**, February, pp. 57–60, February 1992.

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

Johansson, Rolf, M. Magnusson, and P. A. Fransson: "Discrimination of patients with cerebral nervous and peripheral vestibular lesions with human posture dynamics." In Horak and Wollacott, Eds., *Posture and Gait: Control Mechanisms*, pp. 304–307. Univ. of Oregon Books, 1992.

Johansson, Rolf, and Måns Magnusson: "Human postural dynamics." *CRC Critical Reviews in Biomedical Engineering*, **18**, pp. 413–437, 1991.

Karlberg, M., M. Magnusson, and R. Johansson: "Restrained cervical mobility impairs voluntary eye motor." In Horak and Wollacott,

Eds., *Posture and Gait: Control Mechanisms*, pp. 101–104. Univ. of Oregon Books, 1992.

Karlberg, M., M. Magnusson, R. Johansson, E. M. Malmström, A. Melander, and U. Moritz: "Reduced body sway after physiotherapeutic treatment of patients with dizziness and cervical pain." In Horak and Wollacott, Eds., *Posture and Gait: Control Mechanisms*, pp. 396–399. Univ. of Oregon Books, 1992.

Larsson, J. E., and P. Persson: "An expert system interface for an identification program." *Automatica*, **27**, pp. 919–930, 1991.

Magnusson, M., R. Johansson, P. A. Fransson, and M. Karlberg: "Differences in dynamics of human postural control in vestibular neuritis and in patients operated for acoustic neuromas." In Horak and Wollacott, Eds., *Posture and Gait: Control Mechanisms*, pp. 308–310. Univ. of Oregon Books, 1992.

Magnusson, M., R. Johansson, U. Mercke, S. Harris, and G. Sundbärg: "Postural control in subjects with acoustic neurinoma and effects of surgery." In Tos and Thomsen, Eds., *Acoustic Neuroma*, pp. 921–923. Kugler Publications, Amsterdam/New York, 1992.

Nielsen, Lars, and Gunnar Sparr: "Projective area-invariants as an extension of the cross-ratio." *Computer Vision, Graphics, and Image Processing: Image Understanding*, **54**, pp. 145–159, 1991.

Persson, Per: "Stability regions of a model reference control system." *Journal of Guidance, Control, and Dynamics*, **14:3**, pp. 697–698, 1991.

Conference Contributions

Andersson, Leif, and Anders Blomdell: "A real-time programming environment and a real-time kernel." In Asplund, Ed., *National Swedish Symposium on Real-Time Systems*, Technical Report No 30 1991-06-21. Dept. of Computer Systems, Uppsala University, Uppsala, Sweden, 1991.

Andersson, Mats: "Combined object-oriented modelling in Omola." In Stephenson, Ed., *Proceedings of the 1992 European Simulation Multiconference ESM '92*, York, UK, June 1992. Society for Computer Simulation International.

Andersson, Mats: "Discrete event modelling and simulation in Omola." In *Proceedings of the 1992 IEEE Symposium on Computer-Aided Control System Design, CADCS '92*, Napa, California, March 1992.

Andersson, Mats, Sven Erik Mattsson, and Bernt Nilsson: "On the architecture of CACE environments." In *Preprints of the IFAC Symposium Computer Aided Design in Control Systems, CADCS'91*, pp. 63–68, Swansea, UK, 1991.

Årzén, Karl-Erik: "Sequential function charts for knowledge-based, real-time applications." In *Proc. Third IFAC Workshop on AI in Real-Time Control*, Rohnert Park, California, 1991.

Årzén, Karl-Erik: "A survey of commercial real-time expert systems environments." In *IFAC/IFIP/IMACS Symposium on Artificial Intelligence in Real-Time Control*, Delft, The Netherlands, 1992.

Åström, Karl Johan: "Design and implementation of digital and adaptive controllers." In *Preprints 1st IFAC Symposium on Design Methods of Control Systems*, Zurich, Switzerland, 1991. Invited plenary paper.

Åström, Karl Johan: "Intelligent control." In Commault *et al.*, Eds., *Proceedings of the First European Control Conference, ECC 91,* Grenoble, France, volume 3, pp. 2328–2339, Paris, 1991. Hermes. Invited plenary paper.

Åström, Karl Johan: "Autonomous controllers." In *Preprints 1992 IFAC/ IFIP/ IMACS Int. Symp. on Artificial Intelligence in Real-Time Control (AIRTC)*, pp. 1–6, Delft, The Netherlands, 1992. Invited plenary paper.

Åström, Karl Johan: "Evaluation of quadratic loss functions for linear systems." In *Symposium on Fundamentals of Discrete-Time Systems*, Chicago, Illinois, 1992. A meeting in honor of Professor Eliahu I. Jury.

Åström, Karl Johan, Bo Bernhardsson, and Anders Ringdahl: "Solution using robust adaptive pole placement." In Commault *et al.*, Eds., *Proceedings of the First European Control Conference, ECC 91,* Grenoble, France, volume 3, pp. 2340–2345, Paris, 1991. Hermes.

Brück, Dag, T. Burnett, B. van Eijk, P. Kunz, L. Lönnblad, A. Nilsson, and M. H. Seymour: "Standardization of C++." In *Proceedings of the First Workshop on the MC++ Event Generator Toolkit,* Lund, Sweden, January 1992. Document Numbers LU TP 92-4 and Cavendish-HEP-92/1.

Dahl, Ola: "An interactive environment for real time implementation of control systems." In Barker, Ed., *Computer Aided Design in Control Systems,* Preprints of the IFAC Symposium, Swansea, UK, Oxford, UK, 1991. Pergamon Press.

Dahl, Ola: "Path following for a flexible joint robot." In *Preprints SYROCO '91, IFAC/IFIP/IMACS Symposium on Robot Control,* Vienna, Austria, September 1991.

Hagander, Per: "Substrate control in fed-batch cultivations using a mode-based modification of a PI-controller." In *2nd IFAC Symposium on Modelling and Control of Biotechnical Processes,* Keystone, Colorado, March 1992.

Hagander, Per, and Bo Bernhardsson: "A simle but rich test example for H_∞-optimal control." In *Proceedings 1992 American Control Conference,* volume 1, pp. 745–746, Chicago, Illinois, June 1992.

Hägglund, Tore: "A dead-time compensating three-term controller." In *9th IFAC/IFORS Symposium on Identification and System Parameter Estimation,* Budapest, Hungary, 1991.

Hägglund, Tore: "Level estimation in ships based on fault detection." In *IFAC/IMACS Symposium on Fault Detection, Supervision and Safety for Technical Processes,* Baden-Baden, FRG, 1991.

Hägglund, Tore, and Karl Johan Åström: "Identification of systems using periodic excitation." In *9th IFAC/IFORS Symposium on Identification and System Parameter Estimation,* Budapest, Hungary, 1991.

Hansson, Anders: "Control of level-crossings and extremes in stationary gaussian random processes." In *Proceedings of th 30th IEEE Conference on Decision and Control*, Brighton, UK, 1991.

Hansson, Anders: "Control of level-crossings in stationary gaussian random sequences." In *Proceeedings of the 1992 American Control Conference*, Chicago, Illinois, 1992.

Jobling, C. P., and Sven Erik Mattsson: "Model building support—graphical systems input is only part of the solution." In Stephenson, Ed., *Proceedings of the 1992 European Simulation Multiconference ESM '92*, York, UK, June 1992. Society for Computer Simulation International.

Johansson, Rolf, and G. Gennser: "System identification applied to ultrasonic monitoring of blood flow." In *Proc. IEEE Eng. in Medicine and Biology Society Conference*, pp. 1991–1992, Orlando, Florida, 1991.

Johansson, Rolf, M. Magnusson, and P. A. Fransson: "Discrimination of patients with central nervous and peripheral vestibular lesions with human postural dynamics." In *Barany Society Int. Meeting*, Prague, Czechoslovakia, 1992.

Karlberg, M., M. Magnusson, Rolf Johansson, E. M. Malmström, A. Melander, and U. Moritz: "Reduced body sway after physiotherapeutic treatment of patients with dizziness and cervial pain." In *Barany Society Int. Meeting*, Prague, Czechoslovakia, 1992.

Larsson, Jan Eric: "Model-based alarm analysis using MFM." In *Proceedings of the 3rd IFAC International Workshop on Artificial Intelligence in Real-Time Control*, 1991.

Larsson, Jan Eric: "Model-based fault diagnosis using MFM." In *Preprints of the IFAC Symposium on On-Line Fault Detection and Supervision in the Chemical Process Industries*, University of Delaware, Newark, Delaware, 1992.

Larsson, Jan Eric: "Model-based measurement validation using MFM." In *Preprints of the IFAC Symposium on On-Line Fault Detection and Supervision in the Chemical Process Industries*, University of Delaware, Newark, Delaware, 1992.

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.

Mattsson, Sven Erik: "Modelling of power systems in Omola for transient stability studies." In *Proceedings of the 1992 IEEE Symposium on Computer-Aided Control System Design, CADCS '92*, Napa, California, March 1992.

Mattsson, Sven Erik: "Object-oriented modelling of a real continuous-time system." In Stephenson, Ed., *Proceedings of the 1992 European Simulation Multiconference ESM '92*, York, UK, June 1992. Society for Computer Simulation International.

Mattsson, Sven Erik, and Mats Andersson: "Towards a universal modelling language." In *ISA/91 Anaheim Proceedings*. Istrument Society of America, 1991. Invited paper.

Mattsson, Sven Erik, and Mats Andersson: "The ideas behind Omola." In *Proceedings of the 1992 IEEE Symposium on Computer-Aided Control System Design, CADCS '92*, Napa, California, March 1992.

Mattsson, Sven Erik, and Gustaf Söderlind: "A new technique for solving high-index differential-algebraic equations." In *Proceedings of the 1992 IEEE Symposium on Computer-Aided Control System Design, CADCS '92*, Napa, California, March 1992.

Nilsson, Anders, Karl-Erik Årzén, and Tom F. Petti: "Model-based diagnosis—State transition events and constraint equations." In *IFAC Symposium on AI in Real-Time Control*, Delft, The Netherlands, 1992.

Nilsson, Bernt: "Object-oriented chemical process modelling in Omola." In *Proceedings of the 1992 IEEE Symposium on Computer-Aided Control System Design, CADCS '92*, Napa, California, March 1992.

Nilsson, Klas: "An experimental platform for control of industrial robots." In Asplund, Ed., *National Swedish Symposium on Real-Time Systems*, Technical Report No 30 1991-06-21. Dept. of Computer Systems, Uppsala University, Uppsala, Sweden, 1991.

Nilsson, Klas, and Lars Nielsen: "An architecture for application oriented robot programming." In *IEEE International Conference on Robotics and Automation*, Nice, France, 1992.

Rantzer, Anders, and Bo Bernhardsson: "Structured stability margin and the finite argument principle." In *Proceedings IFAC 1st Conference on Design Methods*, Zurich, Switzerland, 1991.

Wittenmark, Björn, and Kjell Gustafsson: "Some issues in digital controller design." In *Preprints European Control Conference ECC '91*, pp. 538–543, Grenoble, Francy, July 1991.

Wittenmark, Björn, and Per-Olof Källén: "Identification and design for robust adaptive control." In *Preprints European Control Conference ECC '91*, pp. 1390–1395, Grenoble, France, July 1991.

Technical Reports

ABB and Dept. of Automatic Control: *Knowledge-Based Real-Time Control Systems*, IT4 Project: Phase II, 1991.

D. Reports

Most of the reports listed below are numbered with "TFRT-" and four numerals. This number is part of the complete report number CODEN: LUTFD2/(TFRT-0000). From March 1992 the reports are numbered with ISRN-numbers.

Dissertations

Dahl, Ola: *Path Constrained Robot Control.* PhD thesis ISRN LUTFD2/TFRT--1038--SE, April 1992.

Gustafsson, Kjell: *Control of Error and Convergence in ODE Solvers.* PhD thesis ISRN LUTFD2/TFRT--1036--SE, March 1992.

Holmberg, Ulf: *Relay Feedback of Simple Systems.* PhD thesis TFRT-1034, August 1991.

Lundh, Michael: *Robust Adaptive Control.* PhD thesis TFRT-1035, December 1991.

Persson, Per: *Towards Autonomous PID Control.* PhD thesis ISRN LUTFD2/TFRT--1037--SE, April 1992.

Lic Tech Theses

Hansson, Anders: *Minimum Risk Control.* Lic Tech thesis TFRT-3210, November 1991.

Källén, Per-Olof: *Frequency Domain Adaptive Control.* Lic Tech thesis ISRN LUTFD2/TFRT--3211--SE, April 1992.

Nilsson, Klas: *Applications Oriented Programming and Control of Industrial Robots.* Lic Tech thesis ISRN LUTFD2/TFRT--3212--SE, June 1992.

Final Reports

Dagnegård, Eva, and Karl Johan Åström: "Activity report 1990–1991." Report TFRT-4019, October 1991.

Master Theses

Andersson, Bo, and Joachim Grebe: "PC-styrning av fjärrvärmeverk," (Computer control of a heating plant). Master thesis TFRT-5451, January 1992.

Balters, Martin: "Adaptive control of piecewise linear systems." Master thesis TFRT-5457, March 1992.

Bernersson, Ola, and Rikard Berglund: "Jämförelse mellan den adaptiva regulatorn Novatune och en PID-regulator," (Comparison between the adaptive controller Novatune and a PID-controller). Master thesis TFRT-5447, December 1991.

Henriksson, Jens, and Björn Törnqvist: "Användning av neurala nätverk som prediktionsmetod vid investeringsanalys," (Use of neural networks as a prediction method in investment analysis). Master thesis ISRN LUTFD2/TFRT--5459--SE, June 1992.

Johansson, Anja: "Process presentation adapted to operator tasks." Master thesis TFRT-5454, March 1992.

Johansson, Jan: "Recursive identification of respiratory parameters." Master thesis ISRN LUTFD2/TFRT--5460--SE, June 1992.

Johansson, Stefan, and Erik Apelgren: "Adaptiv styrning av ubåt," (Adaptive control of a submarine). Master thesis TFRT-5453, February 1992.

Jonasson, Sven: "Interaktiv grafisk editering och simulering av Grafcet," (Interactive graphical editing and simulation of Grafcet). Master thesis TFRT-5456, March 1992.

Josephson, Mikael: "Simulation of a paper finishing flexible system with SIMAN." Master thesis ISRN LUTFD2/TFRT--5458--SE, March 1992.

Krucinski, Martin: "Modelling and control of a dairy filling machine." Master thesis TFRT-5445, November 1991.

McKelvey, Tomas: "Neural networks applied to optimal flight trajectories." Master thesis TFRT-5442, September 1991.

Menander, Fredrik, and Johan Silvander: "Flödesobserverare för asynkronmotor," (Fluxobserver for induction motor). Master thesis TFRT-5448, December 1991.

Nilsson, Anders: "Qualitative model-based diagnosis—MIDAS in G2." Master thesis TFRT-5443, September 1991.

Nilsson, David: "Are expert systems needed on the power exchange?" Master thesis 5440, September 1991.

Nilsson, Håkan: "Implementation of Petri-net and Grafcet primitives in Omola and modelling of Markov-processes." Master thesis TFRT-5452, August 1991.

Persson, Magnus: "Modellering och simulering av kraftnät i Omola," (Modelling and simulation of power systems in Omola). Master thesis TFRT-5455, March 1992.

Petersson, Carl Henrik: "Artificial neural networks—An application for line segment detection in image." Master thesis TFRT-5441, September 1991.

Sandin, Anders, and Sverre Ström-Olsen: "Substratreglering av fedbatch-process," (Substrate control of a fedbatch process). Master thesis TFRT-5444, October 1991.

Sturesson, Helge: "Application of fuzzy logic to automatic control: A case study of the inverted pendulum problem." Master thesis TFRT-5450, December 1991.

Tamras, Istephan: "Digital reglering av AC/DC-omriktare," (Digital control of an AC/DC converter). Master thesis TFRT-5446, December 1991.

Tham, Krister: "Utveckling av system för registrering av andningsaktivitet," (Developing a system for measuring respiratory drive). Master thesis TFRT-5449, December 1991.

Internal Reports

Åström, Karl Johan: "Projekt i adaptiv reglering vt91," (Projects in adaptive control spring '91). Report TFRT-7482, January 1992.

Åström, Karl Johan: "Projekt i adaptiv reglering vt92," (Projects in adaptive control spring '92). Report ISRN LUTFD2/TFRT--7484--SE, June 1992.

Åström, Karl Johan, C. C. Hang, and B. C. Lim: "A new Smith predictor for controlling a process with an integrator and long dead-time." Report ISRN LUTFD2/TFRT--7488--SE, April 1992.

Åström, Karl Johan, and Kanniah Jagannathan: "A DSP implementation of an adaptive controller." Report ISRN LUTFD2/TFRT--7494--SE, March 1992.

Berg, Anders: "Experiments with the back-propagation algorithm." Report ISRN LUTFD2/TFRT--7489--SE, April 1992.

Brück, Dag: "ANSI C++ committee meetings March 11–15 and June 17–21, 1991." Report TFRT-7481, September 1991.

Brück, Dag: "Lund C++ seminars, June 13–14, 1991." Report TFRT-7479, August 1991.

Brück, Dag: "C++ standardization meeting March 15–20, 1992." Report ISRN LUTFD2/TFRT--7491--SE, May 1992.

Hägglund, Tore: "Disturbance supervision in feedback loops." Report TFRT-7483, February 1992.

Hansson, Anders: "Control of level crossing in stationary Gaussian random sequences." Report TFRT-7478, August 1991.

Hansson, Anders: "Minimum upcrossing control of ARMAX-processes." Report ISRN LUTFD2/TFRT--7487--SE, April 1992.

Hansson, Anders: "Optimal modification of reference signals for critical processes using alarm signals." Report ISRN LUTFD2/TFRT--7490--SE, May 1992.

Hansson, Anders: "A stochastic alternative to fuzzy control." Report ISRN LUTFD2/TFRT--7486--SE, April 1992.

Holmberg, Ulf: "Omola models for heat recovery steam generators." Report ISRN LUTFD2/TFRT--7485--SE, April 1992.

Johansson, Rolf, Bo Bernhardsson, Anders Hansson, and Henrik Olsson: "Processidentifiering. Projektarbeten hösten 1991," (System identification. Projects fall 1991). Report TFRT-7492, December 1991.

Sarraut, Patrick: "Implementation of a toolbox for colored Petri nets in G2." Report TFRT-7480, September 1991.

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E. Seminars at the Department

Seminars given at the department during the academic year 1991–1992, are summarized here. They are given both by the staff at the department and by invited lecturers.

1991

Aug 22	Zvi Shiller (UCLA): "On the design and motion planning of articulated systems for minimum time motions."
Aug 29	Håkan Nilsson: "Implementation of Petri-net primitives and modelling of markovprocesses." MSc-thesis presentation.
Aug 30	Per-Olof Gutman (Technion, Israel): "Performance related adaptive friction compensation for uncertain systems."
Aug 30	Bruno Siciliano (Naples): "Robotics research activities at the University of Naples."
Sep 3	David Nilsson: "Are expert systems needed on the power exchange?" MSc-thesis presentation.
Sep 6	Patrick Sarraut: "The implementation of a toolbox for colored Petri nets in G2."
Sep 11	Ola Dahl: "Path following for a flexible joint robot."
Sep 18	Helge Sturesson: "Fuzzy control of an inverted pendulum." MSc-thesis presentation.
Sep 20	Tomas McKelvey: "Neural networks applied to optimal flight trajectories." MSc-thesis presentation.
Sep 20	Anders Nilsson: "Model-based diagnosis: Midas in G2." MSc-thesis presentation.

Sep 25 Per Christer Lund (NTH): "DYMON."

Sep 27 Klas Nilsson: "Application oriented robot programming."

Sep 27 Carl Henrik Petersson: "Artificial neural networks—An application for line segment detection in image." MSc-thesis presentation.

Oct 4 Ulf Holmberg: "Relay feedback of simple systems." Doctoral dissertation defence. Opponent: Derek Atherton (Sussex).

Oct 4 Derek Atherton (Sussex): "Some recent control engineering research at Sussex."

Oct 9 Carlos Canudas de Wit (Grenoble): "Exponential stabilization of a mobile robot with nonholonomic constraints."

Oct 11 Sverre Ström-Olsen and Anders Sandin: "Substratreglering av fedbatch-process." MSc-thesis presentation.

Oct 11 Bengt Mårtensson (FRG): "Non-gradient adaptive control from first principles."

Oct 14 J. P. Alridge (Togai Infralogic): "Recent advances in fuzzy control."

Oct 16 Cleve Moler and John Little (The MathWorks, Inc): "Matlab—Meet the men behind it."

Oct 23 Lino Guzzella (ETH, Zurich): "Translation of the basic concepts from the linear to the nonlinear formulation."

Oct 25 Lino Guzzella (ETH, Zurich): "Solution of some nonlinear control synthesis problems."

Oct 30 Kjell Gustafsson: "The Kjelle-controller—Error control in explicit Runge-Kutta methods."

Oct 31 Peter Lee (Queensland, Australia): "Generic model control—Theory and applications."

Nov 1 Martin Krucinski: "Modelling and control of a dairy filling machine." MSc-thesis presentation.

Nov 20 Richard Weber (Exxon Chemical, New Jersey): "Real-time expert systems—An industrial perspective."

Nov 22 Alexander Medvedev (Luleå): "A sensor fault detection and isolation method."

Nov 26 Peter Shirkov (USSR): "Difference schemes with complex coefficients for complicated stiff problems of mathematical physics."

Nov 27 Jörgen Malmborg: "Sliding mode control for a helicopter model."

Nov 27 Leif Andersson and Kjell Gustafsson: "Computer hotchpotch: Internet, How to get more disk, NA-net and netlib."

Nov 28 Torsten Söderström (Uppsala): "Automatic control and signal processing."

Nov 29 Anders Hansson: "Minimum risk control." Lic Tech dissertation seminar. Reviewer: Torsten Söderström.

Dec 4 Karl-Erik Årzén: "Knowledge-based real-time control systems—Final report."

Dec 18 Rikard Berglund and Ola Bernerson: "Comparison of Novatune and a PID controller." MSc-thesis presentation.

Dec 18 Fredrik Menander and Johan Silvander: "Flux observer for induction motors." MSc-thesis presentation.

Dec 19 Krister Tham: "Developing a system for measuring respiratory drive." MSc-thesis presentation.

1992

Jan 13 Anders Rantzer (KTH): "Computation of value sets (templates) of transfer functions with uncertain parameters."

Jan 23	Huibert Kwakernaak (University of Twente): "Robust Control and H_∞-optimization."
Jan 24	Michael Lundh: "Robust adaptive control." Doctoral dissertation defence. Opponent: Huibert Kwakernak (Twente).
Jan 29	Bo Bernhardsson: "Sampling of a system with several time delays—Bob's Christmas Theorem."
Jan 30	Leif Andersson: "LaTeX" or "If you can't beat 'em, join 'em."
Feb 6	Björn Wittenmark et al: "Highlights from CDC-91."
Feb 20	Karl-Erik Årzén: "A Grafcet-based graphical procedure language." Including a G2 demonstration.
Feb 20	Karl-Erik Årzén: "Report from Workshop on The Design and Analysis of Fuzzy Controllers."
Feb 24	Erik Apelgren and Stefan Johansson: "Adaptive control of a submarine." MSc-thesis presentation.
Feb 27	Arto Marttinen (Espoo, Finland): "A graphical environment for Simnon users."
March 2	Magnus Persson: "Modeling and simulation of power systems using Omola." MSc-thesis presentation.
March 9	Sven Jonasson: "Interactive graphical editing and simulation of Grafcet." MSc-thesis presentation.
March 12	Bo Andersson and Joachim Grebe: "Computer control of a heating plant." MSc-thesis presentation.
March 20	Anja Johansson: "Process presentation adapted to operator tasks." MSc-thesis presentation.
March 27	Martin Balters (ETH, Zurich): "Adaptive control of piecewise linear systems."
March 27	Mikael Josefsson: "Simulation of a paper finishing flexible system with SIMAN." MSc-thesis presentation.

April 3 — Anders Hansson: "On the existence of minimum upcrossing controllers and control of the mean time between failures."

May 5 — Kjell Gustafsson: "Control of error and convergence in implicit ODE solvers."

May 12 — Per Persson: "Design of PID controllers."

May 12 — Anders Helmersson (Saab Ericsson Space): "μ-tools: A toolbox for H_∞ and μ-design."

May 19 — Stephen Murphy (Rensselaer Polytechnic Institute, New York): "Single arm and multiple arm control work at CIRSSE."

May 21 — Ernst Hairer (Genève): "Solving differential-algebraic systems by Runge-Kutta type methods."

May 21 — Assen Todorov (Sofia): "Adaptive control systems with variable structure."

May 22 — Kjell Gustafsson: "Control of error and convergence in ODE solvers." Doctoral dissertation defence. Opponent: Ernst Hairer (Genève).

May 26 — Per-Olof Källén: "Frequency domain adaptive control." Lic Tech dissertation seminar.

June 1 — Klas Nilsson: "Application oriented programming and control of industrial robots." Lic Tech dissertation seminar.

June 2 — Per Persson: "Towards autonomous PID control." Doctoral dissertation defence. Opponent: Jan Sternby (Gambro).

June 3 — Ola Dahl: "Path constrained robot control." Doctoral dissertation defence. Opponent: Mark Spong (University of Illinois).

June 3 — Mark Spong: "Pseudolinearization using spline functions with applications to the acrobot."

June 9 Kjell Gustafsson: "Continuous-time simulation—Traps and pitfalls."

June 12 Jens Henriksson and Björn Törnqvist: "Use of neural networks as a predition method in investment analysis." MSc-thesis presentation.

June 16 Jan Johansson: "Recursive identification of respiratory parameters for sheep." MSc-thesis presentation.

F. Lectures by the Staff

1991

July 3	Kjell Gustafsson: "Controlling numerical integration," Scientific Computation Research Center, Rensselaer Polytechnic Institute, Troy, New York.
July 3	Björn Wittenmark: "Some issues in digital controller design," ECC 91, Grenoble, France.
July 4	Björn Wittenmark: "Identification and design for robust adaptive control," ECC 91, Grenoble, France.
July 5	Karl Johan Åström: "Intelligent control," Invited plenary lecture, ECC 91, Grenoble, France.
July 5	Karl Johan Åström: "Solution using robust adaptive pole placement," ECC 91, Grenoble, France.
July 10	Tore Hägglund: "A dead-time compensating three-term controller," 9th IFAC/IFORS Symposium on Identification and System Parameter Estimation, Budapest, Hungary.
July 11	Tore Hägglund: "Identification of systems using periodic excitation," 9th IFAC/IFORS Symposium on Identification and System Parameter Estimation, Budapest, Hungary.
July 15	Mats Andersson: "On the architecture of CACE environments," IFAC Symposium on Computer Aided Design in Control Systems, Swansea, UK.
July 16	Ola Dahl: "An interactive environment for real time implementation of control systems," IFAC Symposium Computer Aided Design of Control Systems, Swansea, UK.
Aug 19	Leif Andersson and Anders Blomdell: "A real-time programming environment and a real-time kernel," National Swedish Symposium on Real-Time Systems, Uppsala University, Sweden.

Aug 19 Klas Nilsson: "An experimental platform for control of industrial robots," National Swedish Symposium on Real-Time Systems, Uppsala University, Sweden.

Aug 21 Mats Andersson: "An object-oriented language for model representation and simulation of dynamical systems," Institute of Cybernetics, Tallinn, Estonia.

Aug 21 Jan Eric Larsson: "Diagnostic Reasoning Strategies for Means-End Models," Institute of Cybernetics, Tallinn, Estonia.

Sept 4 Karl Johan Åström: "Design and implementation of digital and adaptive controllers," Invited plenary lecture, The First IFAC Symposium on Design Methods of Control Systems, Zurich, Switzerland.

Sep 6 Bo Bernhardsson: "Structured stability margin and the finite argument principle," IFAC 1st Conference on Design Methods, Zurich, Switzerland.

Sept 9 Sven Erik Mattsson: "Towards a universal modelling language," IEE Colloquium Model Building Aids for Dynamic System Simulation, University of Warwick, UK.

Sept 12 Tore Hägglund: "Level estimation in ships based on fault detection," The IFAC/IMACS Symposium on Fault Detection, Supervision and Safety for Technical Processes, Baden-Baden, Germany.

Sept 17 Ola Dahl: "Path following for a flexible joint robot," The IFAC/IFIP/IMACS Symposium on Robot Control, SYROCO'91, Vienna, Austria.

Sept 24 Karl Johan Åström: "Computer science and feedback control in process automation," Konference EDB Værktøjer i Procesautomatisering, Danish Automatic Society, DTH, Lyngby, Denmark.

Sept 24 Karl-Erik Årzén: "Sequential function charts for knowledge-based, real-time applications," Third IFAC Workshop on AI in Real-Time Control, Rohnert Park, California.

Sept 24 Rolf Johansson: "Quadratic optimization of motion coordination and control," Dept Engineering Cybernetics, Norwegian Institute of Technology, Trondheim, Norway.

Sept 24 Jan Eric Larsson: "Model-based alarm analysis using MFM," The 3rd IFAC International Workshop on Artificial Intelligence in Real-Time Control, Rohnert Park, Sonoma, California.

Sept 27 Karl-Erik Årzén: "Knowledge-based control systems, integrated systems," Santa Clara, California.

Sept 27 Jan Eric Larsson: "Diagnostic reasoning strategies using MFM," Advanced Decision Systems, Santa Clara, California.

Oct 1 Dag Brück: "C++ in the future," The Swedish Unix User Group annual meeting, Stockholm, Sweden.

Oct 25 Sven Erik Mattsson: "Omola and OmSim," Department of Automatic Control, Chalmers University, Gothenburg, Sweden

Oct 30 Mats Andersson: "Towards a universal modelling language," ISA/91 (Instrument Society of America), Anaheim, California

Nov 1 Rolf Johansson: "System identification applied to ultrasonic monitoring of blood flow," Invited paper at Engineering in Medicine and Biology Society Conference, Orlando, Florida.

Nov 5 Rolf Johansson: "Deus ex machina—History of control theory," Lund Institute of Technology, Lund, Sweden.

Nov 8 Tore Hägglund: "A dead-time compensating three-term controller," STFI—Swedish Pulp and Paper Research Institute, Stockholm, Sweden.

Nov 11–14 Karl-Erik Årzén: "Knowledge-based real-time control systems," ABB, Västerås, Sweden.

Nov 28 Dag Brück: "C++ as a research tool," The AT&T Technical Seminars, Paris, France.

Dec 12 Anders Hansson: "Control of level-crossings and extremes in stationary gaussian random processes," The 30th IEEE Conference on Decision and Control, Brighton, UK.

1992

Jan 22 Dag Brück: "Standardization of C++," at the First Workshop on the MC++ Event Generator Toolkit, Lund Sweden.

Feb 4 Sven Erik Mattsson: "Omola and OmSim," Honeywell, Phoenix, Arizona.

Feb 14 Michael Lundh: "Robust design of uncertain SISO Systems," ABB Automation, Västerås, Sweden.

Feb 14 Michael Lundh: "Automatic Initialization of Adaptive Controllers," ABB Automation, Västerås, Sweden.

Feb 24 Per Hagander: "Improved PI-regulator for fed-batch substrate control," The third Japanese-Swedish Workshop on Bioprocess Engineering, Tokyo, Japan.

March 5 Michael Lundh: "Robust design of uncertain SISO Systems," Linköpings Tekniska Högskola, Linköping, Sweden.

March 5 Michael Lundh: "Automatic Initialization of Adaptive Controllers," Linköpings Tekniska Högskola, Linköping, Sweden.

March 11 Michael Lundh: "Automatic initialization of adaptive controllers," National University of Singapore, Singapore.

March 17 Mats Andersson: "The ideas behind Omola," 1992 IEEE Symposium on Computer-Aided Control System Design, CADCS '92, Napa, California.

March 17 Sven Erik Mattsson: "Modelling of power systems in Omola for transient stability studies," 1992 IEEE Symposium on Computer-Aided Control System Design, CADCS '92, Napa, California.

March 18 Bernt Nilsson: "Object-oriented chemical process modelling in Omola," 1992 IEEE Symposium on Computer-Aided Control System Design, CADCS '92, Napa, California.

March 19 Sven Erik Mattsson: "A new technique for solving high-index differential-algebraic Equations," The 1992 IEEE Symposium on Computer-Aided Control System Design, CADCS '92, Napa, California.

March 19 Mats Andersson: "Discrete event modelling and simulation in Omola," 1992 IEEE Symposium on Computer-Aided Control System Design, CADCS '92, Napa, California.

March 30 Per Hagander: "Substrate control in fed-batch cultivations using a model-based modification of a PI-regulator," The 2nd IFAC Symposium on Modelling and Control of Biotechnical Processes, Keystone, Colorado.

April 7 Karl Johan Åström: "Relay oscillations," University of California, Santa Barbara, California.

April 14 Karl Johan Åström: "Approaches to intelligent control," Workshop on Intelligent Control, University of California, Santa Barbara, California.

April 23 Jan Eric Larsson: "Model-based measurement validation and fault diagnosis using MFM," IFAC Symposium on On-Line Fault Detection and Supervision in the Chemical Process Industries, University of Delaware, Newark, Delaware.

April 27 Karl-Erik Årzén: "Knowledge-based real-time control systems," University of Delaware, Newark, Delaware.

April 27 Dag Brück: "Standardization of C++," At "Ada vs. C++," and Ada in Norway seminar, Oslo, Norway.

April 27 Michael Lundh: "Robust design of uncertain SISO Systems," University of Newcastle, Newcastle, Australia.

April 28 Dag Brück: "Standardization of C++," At "Ada vs. C++," and Ada in Sweden seminar, Stockholm, Sweden.

April 29 Kjell Gustafsson: "Control of error and convergence in ODE solvers," Department of Scientific Computing, Uppsala University, Uppsala, Sweden.

May 4 Michael Lundh: "Automatic initialization of adaptive controllers," University of Newcastle, Newcastle, Australia.

May 7 Karl Johan Åström: The 1992 Zaborszky lectures, Part I, "Algorithms and applications," Washington University, St Louis, Missouri.

May 8 Karl Johan Åström: The 1992 Zaborszky lectures, Part II, "Stability theory," Washington University, St Louis, Missouri.

May 11 Karl Johan Åström: The 1992 Zaborszky lectures, Part III, "Relay oscillations," Washington University, St Louis, Missouri.

May 13 Klas Nilsson: "An architecture for application oriented robot programming," IEEE Int. Conference on Robotics and Automation, Nice, France.

May 14 Kjell Gustafsson: "Control of error and convergence in ODE solvers," Division of Automatic Control, Department of Electrical Engineering, Linköping University, Linköping, Sweden.

May 15 Kjell Gustafsson: "Control of error and convergence in ODE solvers," Division of Optimization and Systems Theory, Department of Mathematics, Royal Institute of Technology, Stockholm, Sweden.

May 20 Rolf Johansson: "Measurement of postural control," Swedish Vestibular Society Annual Meeting, Lund, Sweden.

June 2 Mats Andersson: "Object-oriented modelling of a real continuous-time system," The 1992 European Simulation Multiconference in York, UK.

June 2 Mats Andersson: "Combined object-oriented modelling in Omola," The 1992 European Simulation Multiconference in York, UK.

June 4 Rolf Johansson: "Discrimination of patients with central nervous and peripheral vestibular lesions with human postural dynamics," Barany Society Int. Meeting, Prague, Czechoslovakia.

June 5 Mats Andersson: "Object-oriented modelling and simulation," University of Cambridge, UK.

June 16 Karl Johan Åström: "Autonomous controllers," Invited plenary paper, AIRTC, Delft, The Netherlands.

June 23 Karl Johan Åström: "Adaptive control—An introduction," Lecture 1 of a Tutorial Workshop on Adaptive Control, 1992 American Control Conference, Chicago, Illinois.

June 23 Björn Wittenmark: "Adaptive algorithms," Lecture 2 of a Tutorial Workshop on Adaptive Control, 1992 American Control Conference, Chicago, Illinois.

June 23 Karl Johan Åström: "Adaptive control theory," Lecture 3 of a Tutorial Workshop on Adaptive Control, 1992 American Control Conference, Chicago, Illinois.

June 23 Karl Johan Åström: "Practical aspects of adaptive control," Lecture 4 of a Tutorial Workshop on Adaptive Control, 1992 American Control Conference, Chicago, Illinois.

June 23 Björn Wittenmark: "Products and case studies," Lecture 5 of a Tutorial Workshop on Adaptive Control, 1992 American Control Conference, Chicago, Illinois.

June 24 Karl Johan Åström: "Intelligence in single loop controllers," 1992 American Control Conference, Chicago, Illinois.

June 24 Anders Hansson: "A simple but rich test example for H_∞-optimal control," paper by P Hagander and B Bernhardsson, 1992 American Control Conference, Chicago, Illinois.

June 24 Anders Hansson: "Control of level-crossings in stationary gaussian random sequences," 1992 American Control Conference, Chicago, Illinois.

June 27 Karl Johan Åström: "Evaluation of quadratic loss functions for linear systems," Symposium on Fundamentals of Discrete-Time systems, Chicago, Illinois. A meeting in honor of Professor Eliahu I. Jury.

June 30 Karl Johan Åström: "How adaptive are adaptive controllers?" Systems and Control—Themes for the nineties, Imperial College, London, UK. A conference in honor of Professor D. Q. Mayne.

G. Travels

Mats Andersson participated in the "IFAC Symposium on Computer Aided Design in Control Systems" in Swansea, Wales, in July 1991, where he presented a paper. In August he visited the Institute of Cybernetics in Tallinn, Estonia. In October he participated in the Instrument Society of America conference, "ISA/91", in Anaheim, California, where he presented a paper. In March 1992 he attended the "IEEE Symposium on Computer Aided Control Systems Design" in Napa, California, where he presented two papers. Finally, in June, he participated in the "European Simulation Multiconference" in York, UK, where he presented two papers. On the way home he visited the University of Cambridge where he also gave a seminar.

Karl-Erik Årzén visited the OECD Halden Research Institute, Norway, in August 1991. In September he spent a week in California, where he attended the "Third IFAC Workshop on AI in Real-Time Control" in Rohnert Park and visited Integrated Systems, Advanced Decision Systems, and Talarian Corporation. In February 1992 he attended a workshop on fuzzy control held at Siemens in Munich, FRG. In April he wisitied University of Delaware, Newark Delaware, where he attended the "IFAC Symposium on On-Line Monitoring and Diagnosis in the Chemical Process Industries."

Karl Johan Åström presented invited plenary lectures at "European Control Conference" in Grenoble, France, at the "1st IFAC Symposium on Design Methods of Control Systems" in Zurich, Switzerland, and at the "IFAC Symposium on Artificial Intelligence in Real Time Control Systems" in Delft, The Netherlands. He also visited Washington University in St Louis, where he gave the Zaborszky lectures, and University of California in Santa Barbara, where he gave an invited lecture series. He lectured at an industrial course on Adaptive Control in London, UK, and he gave a workshop on Adaptive Control in

connection with the "1992 American Control Conference" in Chicago. He also lectured at symposia in honor of Professor Eli Jury in Chicago and Professor David Mayne in London.

Bo Bernhardsson visited "IFAC 1st Conference on Design Methods" in Zurich in September 1991. He also attended a workshop on Robust Control arranged in connection with the conference.

Dag Brück gave an invited lecture at the Swedish Unix User Group annual meeting in October 1991. In November he participated in the ISO/ANSI C++ standardization meeting in Dallas, Texas. In connection with the meeting, he also visited Judy Grass and Andrew Koenig at AT&T Bell Laboratories. Also in November, he gave a presentation at the AT&T Technical Seminars in Paris.

In Januari 1992, Dag Brück participated in the First Workshop on the MC++ Event Generator Toolkit held in Lund, Sweden, and gave a presentation on C++ standardization. In March he participated in the ISO/ANSI C++ standardization meeting in London, UK. On April 1 impressions from this meeting were presented for people from Ericsson and ABB Automation, in Stockholm. In April Dag Brück participated in two seminars called "Ada or C++? When, how and where?" organized by Ada in Sweden and Ada in Norway. He gave a talk on C++ standardization and was a member of the discussion panel.

Ola Dahl participated in the IFAC Symposium "Computer Aided Design of Control Systems" held in Swansea, UK, July 1991, where he presented a paper. In August he visited the "National Swedish Symposium on Real-Time Systems" in Uppsala. He participated and presented a paper at the "IFAC/IFIP/IMACS Symposium on Robot Control, SYROCO'91," held in Vienna, Austria, in September. In May 1992 he visited the "IEEE International Conference on Robotics and Automation" in Nice, France.

Kjell Gustafsson participates in a Scandinavian research group on the design and implementation of integration methods. In February

1992 and June 1992 he participated in meetings at the Norwegian Institute of Technology and the Danish Institute of Technology, respectively.

Per Hagander participated in the following conferences: "The third Japanese Swedish Workshop on Bioprocess Engineering," which was held in Tokyo in February, and "The 2nd IFAC Symposium on Modelling and Control of Biotechnical Processes", held in Keystone, Colorado, in March–April. At both the conferences he presented a paper.

Tore Hägglund participated and presented papers at the conference "9th IFAC/IFORS Symposium on Identification and System Parameter Estimation" in Budapest in July 1991, and at the conference "IFAC/IMACS Symposium on Fault Detection, Supervision and Safety for Technical Processes" in September in Baden-Baden. In December he visited STFI (Swedish Pulp and Paper Research Institute) in Stockholm. In March 1992 he participated and presented a poster at the "DUP Conference" organized by the Swedish National Board for Industrial and Technical Development in Stockholm.

Anders Hansson attended the "30th IEEE Conference on Decision and Control" in Brighton, England, in December 1991, where he presented a paper. He also presented a paper at the "1992 American Control Conference" in Chicago, Illinois, in June 1992.

Rolf Johansson participated in the conference "Barany Society International Meeting" in Prague, Czechoslovakia, in June 1992.

Ulf Jönsson attended the "IEEE Conference on Decision and Control" held in Brighton, UK, in December 1991

Jan Eric Larsson visited the Institute of Cybernetics in Tallinn, Estonia, during the military coup week in August 1991, to give a lecture and see several demonstrations. In September he participated in the "3rd IFAC International Workshop on Artificial Intelligence in Real-Time Control" in Rohnert Park, Sonoma, California, where he

presented a paper. In connection with this he visited Integrated Systems in Santa Clara, Advanced Decision Systems (ADS), and Talarian Corporation in Mountain View. At ADS he gave a presentation. In April 1992 he participated in the "IFAC Symposium on On-Line Fault Detection and Supervision in the Chemical Process Industries" at University of Delaware, Newark, Delaware. He presented one paper, had one poster, and was chairman for a session.

Michael Lundh visited ABB Automation in February 1992. He also visited the Department of Electrical Engineering at LiTH in Linköping in March 1992. Michael Lundh is visiting The Department of Electrical Engineering at University of Newcastle in Australia from March 1992 to February 1993. On his way to Newcastle he visited National University of Singapore.

Sven Erik Mattsson participated in the "IFAC Symposium Computer Aided Design in Control Systems, CADCS'91" in Swansea in July 1991. In September he participated in the "IEE Colloquium Model Building Aids for Dynamic System Simulation" at the University of Warwick. He then also visited the University of Wales in Swansea. In February 1992 he visited Honeywell in Phoenix, Arizona. In March he participated in the "1992 IEEE Symposium on Computer-Aided Control System Design, CADCS '92" held in Napa, California.

Anders Nilsson visited ABB Systems Control, Santa Clara, California, from May to July 1992 as a result of ABB's master thesis award.

Klas Nilsson attended the "1992 IEEE International Conference on Robotics and Automation" in Nice, France.

Henrik Olsson attended the "IEEE Conference on Decision and Control" held in Brighton, UK, in December 1991.

Björn Wittenmark participated in the conferences "European Control Conference" in Grenoble France, "Conference on Decision and

Control" in Brighton UK, and "the American Control Conference" in Chicago USA. Further he lectured at an industrial course in Adaptive Control in London, UK, and at a workshop on Adaptive Control in connection with the ACC.