Activity Report

Automatic Control

1995–1996

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Lund Institute of Technology

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The report is edited by Eva Dagnegård and Tore Hägglund

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Contents

1. Introduction

This report covers the activities at the Department of Automatic Control at Lund Institute of Technology (LTH) from July 1, 1995 to December 31, 1996. This period differs from previous reports, which covered an academic year from July 1 to June 30. The reason for the change is that Lund University has changed its fiscal year.

The budget for the period July 1, 1995, to December 31, 1996, was 31 MSEK. This corresponds to 21 MSEK per year, which is the same budget as for the previous financial year.

Three PhD theses by Henrik Olsson, Klas Nilsson, and Ulf Jönsson were completed, which brings the total number of PhDs graduating from our department to 47. Henrik Olsson now works for Daimler-Benz in Berlin, Klas Nilsson for ABB Robotics, and Ulf Jönsson has a post doc at Caltech. Two Lic Tech theses by Lars Malcolm Pedersen and Johan Nilsson were defended. We have employed four new PhD students: Mattias Grundelius, Magnus Gäfvert, Hélène Panagopoulos, and Martin Öhman.

In the civ.ing. program we have eight courses. The total number of students who finished the courses were 1011. Fortyone students completed their master's theses. The total teaching effort corresponds to about 150 full-year equivalents. The impact of Europe has been clearly noticeable. A total of 17 students from 6 countries have taken our courses, and 15 have completed their master's theses.

Significant efforts have been made to improve the control laboratory. New computers, new laboratory processes, and new software have been introduced. A substantial effort has also been devoted to development of new man-machine interfaces for laboratory experiments in the basic courses. New computer-based teaching tools have also been explored.

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

The 13th World Congress of the International Federation of Automatic Control (IFAC) was one of the highlights of the year. This conference is held triannually and the reviewing is very critical. At that conference we contributed with an invited plenary lecture and 16 papers among the 1500 papers presented. Karl Henrik Johansson and Anders Rantzer received the Young Author Prize at that conference.

Other highlights of the year was that Rolf Johansson received the 1995 biomedical engineering prize (The Ebeling Prize), that Per Hagander was appointed to “Biträdande Professor” in October 1995, and that K. J. Åström was elected as a foreign associate of the National Academy of Engineering (NAE), USA.

This year, our retrospective chapter, Chapter 6, describes the project on Automatic tuning. This project started in the beginning of the eighties as a small side project to our adaptive control projects. Quite soon it turned out to be a major project with large impacts on future research as well as industrial products.

Some statistics of our reseaerch output is given in the table below. Notice that the entry 95-96 covers a period of 1.5 years.

	90/91	91/92	92/93	93/94	94/95	95-96	Sum
Books	1	0	1	0	2	1	5
Papers	17	15	19	18	17	30	116
Conference papers	47	41	26	29	24	71	238
PhD theses	2	5	2	1	3	3	16
Licentiate theses	0	3	0	0	0	2	5
Master theses	15	21	14	34	23	40	147
Internal reports	23	16	16	16	15	18	104

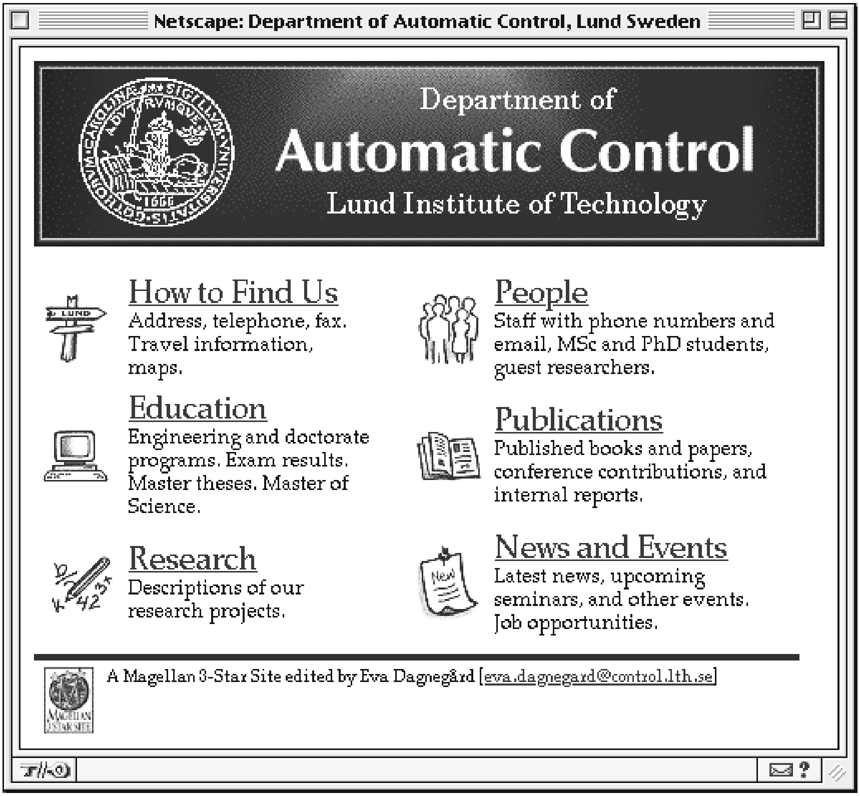
Acknowledgements

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

2. Internet Services

World Wide Web

Our homepage first appeared on the World Wide Web (WWW) in April 1994. With no experience but with lots of ideas we tried to find a suitable web structure. A year later we made a major re-organization



and a new consistent layout. Since then, several more pages have been added, and the information has constantly been updated. You find the homepage at this address:

`http://www.control.lth.se`

Our web site contains information about personnel, education and MSc theses, research, publications, seminars, addresses and telephone numbers, and many other things. It is under continuous development.

Electronic Mail

All personnel can be contacted by electronic mail. A personal email address consists of the full name and the department address, written in the form `FirstName.LastName@control.lth.se`. Double names are separated by underline, hyphens are treated as ordinary characters, and accents are ignored. Examples:

```
karl_johan.astrom@control.lth.se
bjorn.wittenmark@control.lth.se
karl-erik.arzen@control.lth.se
```

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

`control@control.lth.se`

Letters to this address are continuously read by the postmaster and forwarded to the appropriate receiver.

Anonymous FTP

Via FTP you have access to various documents. The URL is:

`ftp://ftp.control.lth.se/pub`

Under the subdirectory *`cace`* you find documents regarding Computer Aided Control Engineering (CACE) and the program OmSim. There are versions of OmSim for Sun-4 workstations and HP workstations under the X Window System or PCs running under the operating system Linux. OmSim is implemented in C++ and uses only public domain software.

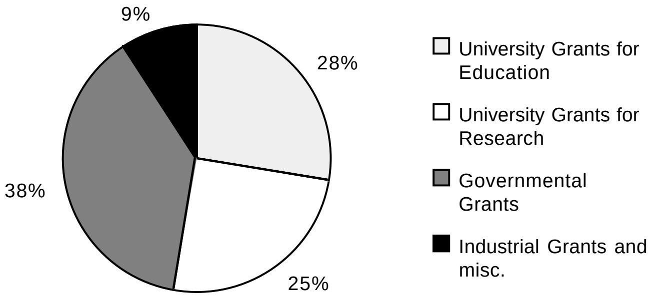
Under `books` you find material regarding the books *Adaptive Control* and *Computer-Controlled Systems*, both written by K. J. Åström and B. Wittenmark. Some of this material is used in the engineering courses.

During this report period the subdirectory for Adaptive Control has been accessed from 287 different sites. The number for CACE is 644 sites, of which 236 have downloaded OmSim.

3. Economy and Facilities

Economy

The income for the one and a half year period between July 1 1995 and December 31 1996 was 31 MSEK, including rent for offices and laboratories. This gives a mean of 21 MSEK per year, which is the same budget as for the previous financial year. The income comes from the University, 53%, and from external grants. The distribution is shown below.



Facilities

The main facilites are laboratories and computer systems. Our main computing resource is a network of Unix workstations. All members of the department have workstations on their desks that are connected to this network. The system was upgraded with funding provided by TFR. A number of workstations were replaced and a new file server and compute server (Sun UltraEnterprise 3000) was installed.

The teaching laboratories are based on desktop processes and personal computers. These laboratories are used in all our courses. The introductory courses give a heavy load on the teaching laboratories because of the large number of students. The total load of the teaching laboratory is 14,608 student hours. This means that each of our 1000 students on the average spends over 14 hours in the lab.

Lab processes that are used most frequently are tank systems, servos, and ball and beam systems. These have all been developed at the department. Development of an inverted pendulum of the TIT configuration has started. We have acquired flexible servos from Educational Control Products, and a “Pendubot” from University of Illinois at Urbana-Champaign. The robotics laboratory was equipped with pneumatic gripper equipment, an (inverted) pendulum for benchmark problems and a dedicated TCP/IP connection to improve teleoperation and sensor data communication between laboratory units.

The development of software for real time control has continued. The main effort has been devoted to finding ways of using Windows NT as a real time operating system so that the powerful user interface programs available for this system may be combined with control software, at least for moderate demands on the sampling frequency. We have developed user interfaces using InTouch from Wonderware Corp. and SattLine from Alfa Laval Automation.

4. Education

Engineering Program

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

Automatic control courses are taught as part of the engineering curricula in Engineering Physics (F), Electrical Engineering (E), Computer Engineering (D), Mechanical Engineering (M), and Chemical Engineering (K). The courses given at the department are listed in Table 1.

Previous years, statistics have been made concerning the “academic year”, which is the year between July 1 and June 31. During the academic year 1995/96, 706 students passed our courses, and 31 students made their master-thesis projects at our department. We now leave the academic year and look at the calendar year 1996. During 1996, 615 students passed our courses and 25 students made master-thesis projects. The teaching load, number of registered students, corresponded to 102 full-year equivalents during 1996 and the average passing rate was 80%.

There were 41 students who completed their master theses during the period 1 July 1995 to 31 December 1996. The theses concerned the following areas: Linear systems (3), Nonlinear systems (4), Adaptive control (5), Modeling and simulation (6), Identification (1), Control design (4), Optimization (1), Real-time systems (4), Robotics and servo systems (5), Fuzzy control (1), Marine control problems (5), and Education tools (3). A list of the master theses is given in Chapter 11.

Table 1. Courses in the engineering program given at the department. The figures show the number of students that passed our courses during fall 1995, spring 1996, and fall 1996.

Course	F95	S96	F96
Reglerteknik AK–FED *FRT010* (Automatic Control, basic course)	279	37	205
Reglerteknik AK–M *FRT060* (Automatic Control, basic course)	25	97	10
Processreglering (K) *FRT080* (Automatic Process Control)	25	102	13
Digital Reglering (FED) *FRT020* (Computer-Controlled Systems)	9	50	9
Realtidsystem (FED) *FRT031* (Real-Time Systems)	32	3	47
Processidentifiering (FED) *FRT040* (System Identification)	3	12	0
Adaptiv reglering (FED) *FRT050* (Adaptive Control)	20	0	19
Olinjär reglering och Servosystem (M) *FRT075* (Nonlinear Control and Servo Systems)	3	9	2
Examensarbete 15 poäng *FRT815* (Master-thesis project, 3 months)	12	6	4
Examensarbete 20 poäng *FRT820* (Master-thesis project, 4 months)	4	9	6
Total amount for the academic year 1995/96	737		
Total amount for the calender year 1996		640	

Computer-Controlled Systems

The third edition of the book Computer-Controlled Systems has been published. Major changes have been made in this edition. The changes are motivated from changes in technology and experiences from teaching to academic and industrial audiences. The material has been reorganized drastically and more than half of the text is rewritten. New material has been added and many new results have been included. Matlab and Simulink are used throughout the book. The changes have been accomplished without increasing the size of the book.

Interactive Learning Tools

We have started experiments with new interactive learning tools. The idea is to provide students with tools that help them to understand control system fundamentals and techniques. Several ideas are pursued. One is based on the concept of *generalized spread sheets*. The spread sheets are generalized by allowing graphical windows with direct manipulation. Different representations of systems are kept in different windows and the relations are maintained during direct manipulations. Such tools are ideal to illustrate the relations between time- and frequency domains and different representations such as pole-zero plots, Nyquist and Bode curves, root loci etc. They can also be used for many other purposes. Systems of this type can be implemented in Matlab.

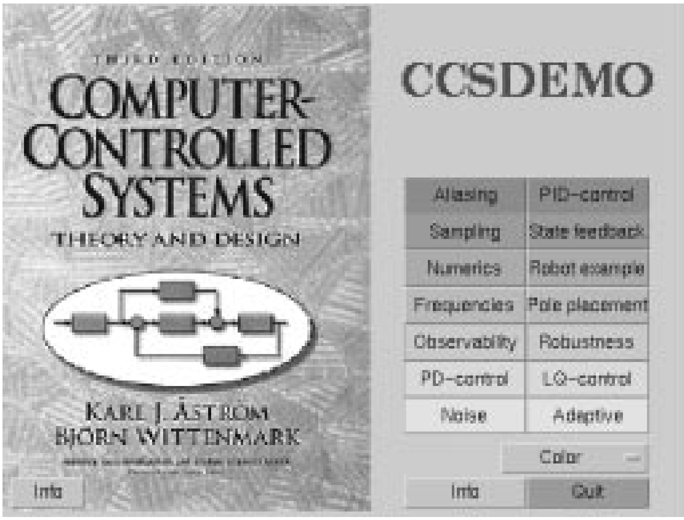


Figure 4.1 Matlab-based computer tool to illustrate the concepts in the course *Computer-Controlled Systems*.

A collection of Matlab modules have been developed for the course "Computer-Controlled Systems" and are available for the students at Internet via the homepage of the course. Theoretical parts are introduced via simulations and a graphical user interface. Modules are available, for instance, for

- Relation between continuous-time and discrete-time systems
- Aliasing
- Observability
- Tuning of PID controllers
- Influence of design parameters in pole-placement and linear-quadratic design
- Numerical aspects of implementation of controllers

The start-up page for this tool is shown in Figure 4.1.

Revision of the Control Laboratory

A substantial effort has been made to revise the laboratory experiments used in our introductory courses. New PCs running Windows NT have been acquired. Our real time kernel has been modified to run under Windows NT and new man machine interfaces have been developed for the tank processes using the commercial software InTouch, see Figure 4.2.

The new interface has had a significant impact on teaching. It is now much easier for the students to focus on the essentials and they learn much faster. The experiments have also been revised and new manuals have been written. The work was carried out by a team lead by Charlotta Johansson and Mats Åkesson. The system has been very well received by the students.

A new inverted pendulum based on the design made by Prof Furuta at Tokyo Institute of Technology has been developed. A first prototype was built and tested. Based on that a second prototype based on commercial components has been built. The system is very well suited for a wide range of experiments in linear and nonlinear control.

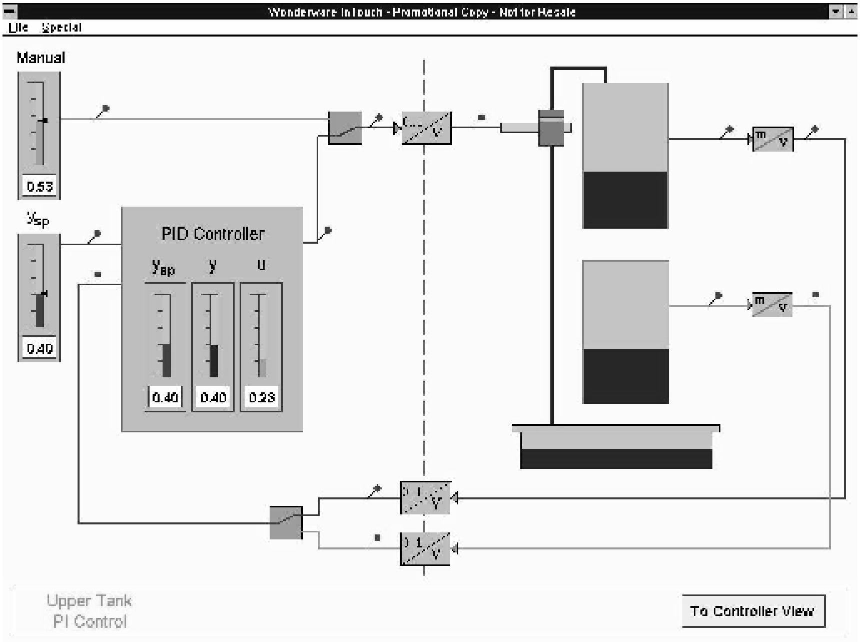


Figure 4.2 Man-machine interface for the level control process.

Industrial Process Control Systems

Sequential logic is a major part of an industrial control system. Typical systems have graphical tools for creating, visualizing and manipulating control sequences. Such systems are well suited for teaching. It is also attractive for students to use industrial control systems in order to get a flavor of the software environments that are common in industry.

Two laboratory exercises have been implemented in SattLine, an environment for process automation. This environment supports the use of a "SoftPLC" which means that the program is executed in a regular PC instead of special hardware. An interface between SattLine and the standard I/O-boards used at the department have been developed as a project in our course on Real-time Systems. This interface together with the "SoftPLC" make it possible to run SattLine

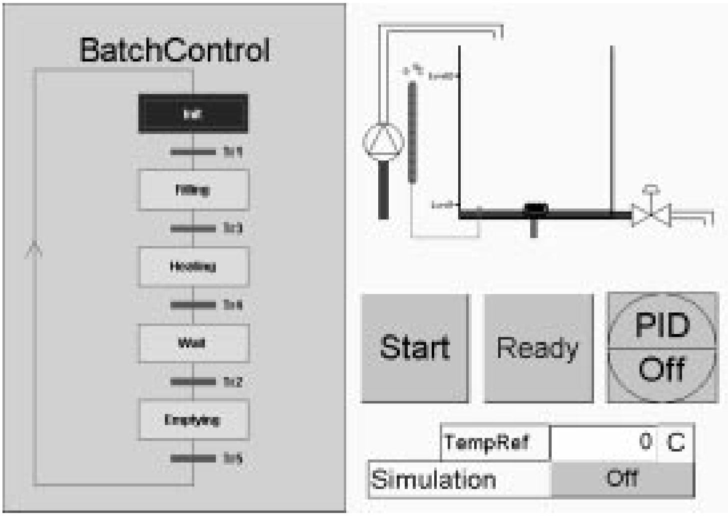


Figure 4.3 Man-machine interface for the soft PLC.

on a single PC Pentium machine without hardware extensions.

Figure 4.3 shows the operator view in the Batch Reactor Laboratory for the course on Process Control. In this laboratory the students implement a control program which combines sequential logic and continuous control. The control sequences are conveniently constructed using graphical programming. It has the advantage that the students can focus on the control problem rather than programming issues.

Doctorate Program

Three PhD theses have been completed during the period: Henrik Olsson (1996), Klas Nilsson (1996), and Ulf Jönsson (1996). This brings the total number of PhDs graduating from our department to 47. Two Lic Tech theses were defended: Lars Malcolm Pedersen (1995) and Johan Nilsson (1996). Abstracts of the theses are given in Chapter 8.

Four new PhD students have been admitted to the department: Mattias Grundelius, Magnus Gäfvert, Hélène Panagopoulos, and Martin Öhman.

The following PhD courses were given:

- Control System Design (B. Bernhardsson) 5+3 points
- History of Control (K. J. Åström) 2 points
- Hilbert Space Theory (B. Bernhardsson) 3 points
- Object Oriented Petri Nets (K.-E. Årzèn) 5 points
- Fuzzy Control (K.-E. Årzèn) 5 points
- Stochastic Systems (B. Bernhardsson) 2 points
- Object-Oriented Modeling of Hybrid Technical Systems 4 points (S. E. Mattsson)
- PID-Control (K. J. Åström, T. Hägglund) 5 points
- Design of Concurrent Systems (B. Sandén,) 2 points
- Optimal Control (A. Rantzer, H. Sussman) 5 points
- Linear Systems 1 (P. Hagander) 5 points
- Linear Systems 2 (P. Hagander) 5 points
- Subspace Model Identification (M. Verhaegen) 2 points
- Modeling of Multibody Systems (M. Otter) 2 points
- Fundamental Limitations in Filtering and Control (M. Seron, J. Braslavsky) 2 points

Information

We have produced information sheets about engineering courses and doctorate program, which have been handed out to the students.

Many students have access to Internet via Lund University. Therefore we have made a great effort to present the education on web pages. Each course in the engineering program has its own homepage, where the students can find course plans, documentation, manuals, old exams, etc. See the URL:

`http://www.control.lth.se/education.html`

5. Research

The goal of the department is to provide students with a solid theoretical foundation combined with a good engineering ability. This is reflected in the research program which, broadly speaking, is divided into theory and applications. The roles of the universities in technology transfer has recently been emphasized in Swedish research policy as the “the third mission.” This means that we now also have responsibility for transfer of research to industry.

The purpose of the theory activity is to develop new ideas, concepts and theories that capture the essence of real control problems. We are of course delighted to find applications of the theory but the focus is always on methodology. In the applications projects the goal is to solve real control problems together with external partners. In these projects the problems are approached with an open mind without glancing at particular methods. One purpose is to learn about real problems, another is to learn about new problems that are suitable for theoretical research. The applications projects also provide very good background for our educational activities.

Technology transfer takes many forms. One is to take results from our research and present them so that they are easy to use. Probably the best way to do this is through personal exchange between industry and university. Students are a very effective vehicle for the transfer.

Realizing that the majority of the research is done outside Sweden another important role for universities in a small country is to take existing knowledge and organize it in such a way that the results can easily be digested by engineers in industry. There is naturally a strong symbiosis with teaching in this activity. A good mechanism is thus to introduce new research material into existing and new courses. A related form of technology transfer is to write books and monographs and to develop software. We have been active in technology transfer for a long time, good examples of this type of exchange where we have transferred ideas are self-tuning control, automatic tuning and computer-aided control engineering. More details have been presented in previous activity reports.

The major research areas are:

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

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

Tuning, Adaptation, and Robust Control

This section covers research projects that are related to adaptive and robust control.

Adaptive Control of Systems with Friction, Hysteresis and Backlash

Researchers: Karl Johan Åström, Magnus Gäfvert, and Henrik Olsson

The work in adaptive control of nonlinear systems focuses on special classes of nonlinearities such as friction, backlash and dead-zone. The structure of the particular nonlinearity is then used in the development of adaptive schemes.

The work on control systems with friction has progressed and resulted in a doctoral dissertation (Henrik Olsson 1995). Tools for analyzing friction-generated limit-cycles has been developed. These are extensions of tools which already exists for relay oscillations. The new tools make it possible to numerically compute the exact shape and stability of friction-generated limit-cycles. Friction compensation has also been examined. In particular the nature of the resulting control error has been explored. The investigation indicates how the parameters of the friction compensation algorithm should be changed adaptively. A master's thesis project has also been initiated which aims at further clarifying the behavior of and relation between various friction models.

Two master theses has been completed treating adaptive control of systems with back-lash. The projects have investigated different adaptive approaches to compensation of the back-lash.

We have made good use of the possibilities to interact with other universities in the Human Capital and Mobility Network on *Nonlinear and Adaptive Control*. In particular we have cooperated with Laboratoire d'Automatique de Grenoble, France.

Control of Uncertain Systems

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

Recent developments in control theory are characterized by rapid improvements of computational tools for design, analysis and simulation. This process is closely linked to theoretical progress in optimization theory and complex analysis. The aim of this project is to pursue this combined development of theoretical and computational tools, in directions motivated by industrial problems.

The main computational tool is non-smooth convex optimization based on linear matrix inequalities. Very effective algorithms have recently been developed for such problems. The theoretical challenge is to formulate practically important design and analysis problems, that can be recast into this form. The historical development of control theory encourages this approach, since the literature contains numerous examples of challenging problems for which no computational tool was available at the time of their statement, but which now can be successfully addressed with the new methods.

Many of the problems that can be solved in this way are in one way or another related to search for Lyapunov functions. This category includes well known analysis techniques based on structured singular values or quadratic stability and also synthesis methods based on optimal control with an LQG or H_∞ criterion. Our most recent research advancements show that many classical results which can be related to existence of a globally quadratic Lyapunov functions, can be greatly improved in either of two ways. One is to introduce more freedom in the optimization by increasing the dimension of the state space. This has proved to be effective in analysis of friction and hysteresis. The other way is to split the state space into smaller regions and allow for piecewise quadratic Lyapunov functions rather than globally quadratic. This appears to have a strong potential for systems with gain-scheduled or hybrid controllers.

Another research topic in this area, motivated by a variety of engineering applications, is to find the smallest real perturbation of a matrix that changes its rank. During August 1996 Li Qiu from HongKong University visited the departement. This visit resulted in a joint paper where our previous formula for the so called real perturbation values, τ_k, was extended from $k = 1$ to general k.

Modeling with Quantified Accuracy

Researchers: Lennart Andersson, Carolyn Beck, Sven Erik Mattsson, and Anders Rantzer

This project has a two-fold background: experiences of object oriented modeling techniques from the Omola project and recent developments in robustness analysis. To deal with uncertainties we need concepts to describe them and tools for working with them. If a model is developed from measured data using system identification methods we can get various statistical measures describing uncertainties. When models are developed from first principles, approximations are sources to uncertainties.

Mathematical tools for quantification of accuracy have been developed in the context of robust control. For example, the notions structured uncertainty and linear fractional transformations, have been introduced to study model accuracy systematically by taking into account the nature of neglected dynamics or parameter deviations.

As a PhD student at Caltech, Carolyn Beck developed these methods towards systematic techniques for reduction of uncertain models, minimizing an error measure. In the autumn of 1995, Lennart Andersson spent a semester at Caltech and started cooperation with Beck. Their joint work continued in the spring as Beck was a postdoc in Lund.

Current activities in the project aim to make the methods more flexible by using more detailed descriptions of signals and perturbations. The original work by Beck is entirely based on L_2-gain bounds. This is sufficient for some applications, but there is a definitive potential for refinements. To identify the needs further, we consider various models from other projects. In particular, a model for a nuclear power plant is studied in cooperation with Electricite de France in Paris.

Multi-Loop Control Systems

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

Controlling a plant in process industry is a very large and complex problem. By tradition, it is solved by splitting up the problem into design of many simple control loops. This has proved to be a rather successful approach, however at the cost of possible limitations on the overall plant performance. It is well-known that the simple control loops can influence each other and cause degradation in the achievable control quality for each process output. It is therefore important to select the control loops carefully. In this project systematic ways of choosing control structures are investigated. Limitations imposed by a diagonal control structure have been quantified and the implications on sequential control design have been shown.

Another aim of this project is to develop simple practical experiments on which the choice of control structure and the control design can be build. Relay feedback is known as a robust method for tuning PID controllers in SISO settings, and the approach seems to be promising also for multi-loop systems. Some generic behaviors of relay feedback systems have been derived. In particular, a thorough analysis of third-order systems has been done. It has been shown that the existence of fast switches and sliding modes is completely characterized by the high-frequency asymptote of the Nyquist curve for the linear part of the system. Also, a novel method for global analysis of relay feedback systems has been introduced.

Collaboration with Professor Bryant's group at the Centre for Process Systems Engineering at Imperial College in London started with a one week meeting in Lund in May 1996.

Hybrid Systems

Researchers: Karl Johan Åström, Bo Bernhardsson, and Jörgen Malmborg

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

In this project it is attempted to use switching strategies to improve the performance of simple controllers and facilitate controller design. During 1996 we have implemented a hybrid control system consisting of a time optimal controller and a PID controller together with a switching algorithm. The system shows very good performance when controlling the levels of a double tank system. We have also investigated how simulation tools can be improved to give better results for hybrid systems. A special problem area is discontinuous differential equations.

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

Automatic Tuning of PID Controllers

Researchers: Karl Johan Åström, Tore Hägglund, and Hélène Panagopoulos

This project has been in progress for over ten years, and resulted in industrial products as well as several PhD thesis. A monograph on PID control that is based on experiences obtained in the project has also been published.

During the last year, the project has focused on improvements of PID controller design. Numerically robust design procedures for PI and PID controllers are currently under development. A new simple design method, called the Kappa-Tua method, has also been developed. The method can be applied both when a complete process transfer function is known, and when the process dynamics is given only in terms of three parameters obtained from a step response or a frequency response. The methods are immediately useful for both manual and automatic tuning. Some results have already been transferred to industry (Beijer Electronics AB in Malmö).

Autonomous Control

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

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

The autonomous controller contains a wide range of algorithms and methods of quite different nature. It includes traditional real-time computations, sequential methods for loop assessment and tuning, and knowledge-based methods. Since all these methods must be put into the same framework, one obtains a typical hybrid system. We have a G2 prototype implementation using extended Grafcet for structuring the control algorithms. A detailed example for automatic tuning combined with valve diagnostics has been implemented.

Integrated Control and Diagnosis

Researchers: Mats Åkesson, and Karl-Erik Årzén

The goal of this project is development of methods for integrated design of control and diagnosis functions, development of model-based diagnosis techniques, and implementational issues of on-line diagnosis systems. The work during this year has been focused on three topics: integrated design of control and diagnosis systems using the 4 degree-of-freedom approach, model-based diagnosis of mode changing processes, and sequential function charts for alarm filtering.

A case study of H_∞ based 4 degree-of-freedom controllers has been performed. The approach has been tested on a mechanical servo process with good results.

The work on diagnosis of mode-changing processes combines DMP, a model-based diagnosis framework, with Grafchart, a Grafcet toolbox. The objective is diagnosis of medium-to-large size industrial processes consisting of a number of interconnected equipment units and that have different operating modes. For this type of process the process model typically consists of a number of "local" models. Each local model could represent an equipment unit in a certain operating mode. Typically, the models are a combination of linear and nonlinear models, and of static and dynamic models. In a certain operating mode only a subset of the models are valid and only a subset of the total number of possible faults may occur. The approach is based on encapsulating models and modeled faults within the macro steps and steps of the sequential function chart that implement the sequence control logic for changing the modes.

Sequential function charts are also used for implementing temporal event filters. The objective is to use temporal pattern matching to aggregate low-level alarms into high-level alarms. The approach is based on using state machines for formal language string detection.

System Identification

Researcher: Rolf Johansson

An identification algorithm that effectively fits continuous-time transfer functions and finite-bandwidth noise models to data has been published. Analysis of this class of algorithms proves convergence properties similar to that of maximum-likelihood identification of (discrete-time) ARMAX models. A substantial improvement of the identification accuracy of continuous-time zeros appears to be an important and attractive property of the new algorithm.

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

Professor Michel Verhaegen, TU Delft, The Netherlands, visited the department during August-September 1996 for cooperation on subspace model identification for continuous-time systems. His visit was supported by the Hörjel Foundation.

Computer Aided Control Engineering

Computer Aided Control Engineering, CACE, has been a major area of research at the department for a long time. It has the dual purpose of providing tools for making control engineering much more cost effective and it also provides a glue between many different research projects.

During this academic year the focus has been on development of tools for modeling and simulation of hybrid systems and major applications have been power generation and power distribution. We have started to work on methods for model validation and model simplification.

Modeling and Simulation of Complex Systems

Researchers: Jonas Eborn, Sven Erik Mattsson, Bernt Nilsson, Tomas Schönthal, and James Sørlie

The main aim is to develop methods and computer tools which support development and use of mathematical models. The basic idea is to support reuse so a model component can be used as a part in different applications to solve a variety of problems. Good model libraries should allow a user to make the desired model simply by combining components. Computer tools shall automate the analysis and manipulation, which the user have to do manually today to get the problem on a form that is efficient for numerical solution.

The results include an object-oriented modeling language called Omola and the interactive environment OmSim for development and simulation of Omola models. The usefulness of Omola and OmSim has been demonstrated in a number of applications: chemical processes, power generation, power networks, towed sonar arrays, adaptive control etc. OmSim is a prototype environment and not a full-fledged professional and commercial product. The aim has been to develop and implement an environment that can be used in academia and industry for feasibility studies and as a basis for further research and commercial products. OmSim is available from the department via anonymous FTP, see Section 2. Information is available also via WWW at URL: `http://www.control.lth.se/~cace`.

Our research focuses currently on hybrid systems which contain both continuous time parts and discrete event parts. Omola and OmSim support hybrid models. Differential-algebraic equations is the natural framework for continuous time behavior. There is no such uniform formalism for representing discrete event systems. Omola supports logical conditions to define firing of discrete events and equations to describe the effects of the events. These primitives allow implementation of high level descriptions as Petri nets and Grafcet. This project supports our other projects on Hybrid systems.

A major problem in simulation is to determine the new state after a discrete event, since it means solution of non-linear equation systems with both real and integer unknowns. We are developing a method based on continuation to handle ideal relay switches. The problem is difficult because the system may exhibit sliding mode behavior, so the idealized model has no solution in traditional meaning.There are control design methods which aim for sliding mode behavior, so it is of real interest to simulate such behavior efficiently. The method detects that and generates instead generalized solutions as defined by the Russian mathematician Filippov.

We are also involved in a new project to develop a uniform and standardized object-oriented modeling language. The project is a part of the ESPRIT project “Simulation in Europe, Basic Research Working Group, SiE-WG”. There are already several modeling languages for object-oriented, non-causal modeling, such as Dymola, gPROMS, MOSES, NMF, Omola and U.L.M. There is much experience of using them in various application domains. The aim is to unify the concepts and introduce a common basic syntax and semantics. Information is available via WWW at URL: `http://www.Dynasim.se/language-design`.

Modeling and Control of Energy Processes

Researchers: Karl Johan Åström, Rodney Bell, Jonas Eborn, Sven Erik Mattsson, Bernt Nilsson, and Martin Öhman

The main aim of the project is to develop methods and computer tools that support development, analysis and use of mathematical models in energy process applications. This project is a cooperation with Sydkraft Konsult AB.

In an earlier joint project with Sydkraft we have developed a set of model libraries called K2 with basic models for thermal power generation. The models are developed in Omola and are separated into three levels: systems, units and subunits. Systems are application oriented models described as a structure of units. Examples of systems are the pan section, the condenser section etc. Unit models are commonly used system components like pumps, valves, heat exchangers etc. Subunit models describe particular phenomena like a volume of medium with dynamic mass and energy or flow resistors with variable friction loss.

New improved simplified models have been developed for the steam generation process. The work has been done in collaboration with Dr Rodney Bell of Macquarie University in Australia. The key idea is to develop simple nonlinear models based on physics that capture the key phenomena. The new model captures the crucial shrink-and-swell phenomenon of the liquid level in drum boiler much better.

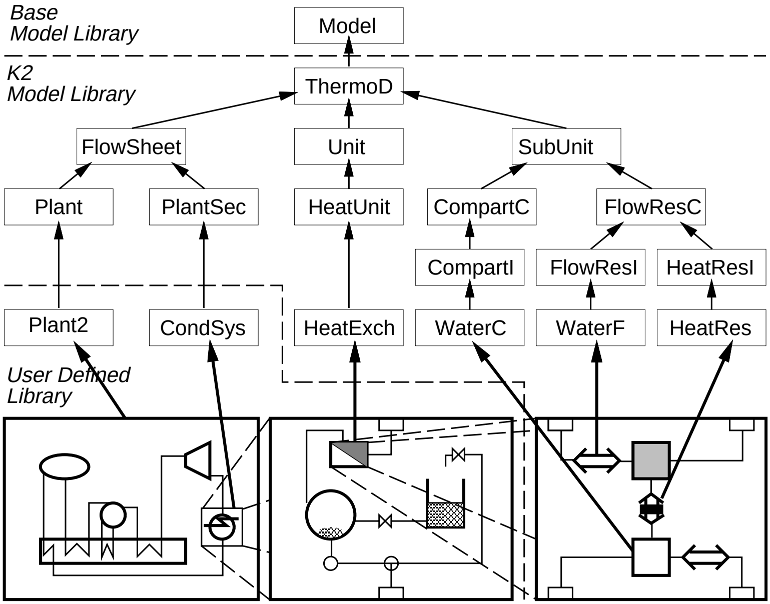


Figure 5.1 The architecture of the K2 model libraries.

A model library must be validated to be of industrial value. Models can be validated in various ways. However, there is no systematic approach to model validation as far as we know. We have started to work on this. The goal will be to validate the models in the K2 model libraries and measured data from the combined cycle power plant in Värnamo, Sweden will be used. The plant is composed of a gas turbine and a heat recovery steam generation cycle. Combustion of fuel gas is done in a conventional gas turbine for production of electric power. The exhaust gas enters heat exchangers and boilers for steam generation. The produced steam is expanded in a steam turbine to produce electric power. Remaining heat is used to produce hot water for district heating.

Today simulation and optimization are the major areas of usage of large complex mathematical models. It is common engineering practice to work with as simple models as possible, because they are easier to analyze and evaluate. For design of controllers, simple time-invariant linear models are used in most cases. There are a well-established theory and commercial computer tools for design of controllers with given specifications. To verify that the controller works well also in reality simulation with more complex models is used. It would be very nice if there were methods and tools for extracting simple models for specific purposes from a large complex model. For linear models there are well-established approaches to model simplification or model reduction. This project puts the user in focus. The aim is to provide tools for exploration of the model to investigate dependences between variables and impacts of terms in equations to see if terms or dynamics can be neglected or if non-linear relations can be replaced by linear ones.

Modeling of Electricity Distribution Networks and Components

Researchers: Bo Bernhardsson, Sven Erik Mattsson, and Erik Möllerstedt

The increased use of switched power supplies and power electronics for motor control create disturbances in the wave form of the supplied electricity, which ideally should be sinusoidal with constant frequency and amplitude. These disturbances can be compensated for by inserting electronic devices near to the load. Furthermore, the deregulation of the electrical power market means that a distribution company must supply electrical power of high quality and it must be able to solve its customers' problems. Consequently, there are strong needs and demands for computer aided tools.

The aim of this project is to develop model libraries, methods and tools for static and dynamic simulation of electricity distribution networks. The models need to be non-linear and accurate up to frequencies of a few kHz. This means that the approach taken for transient studies of power transmission networks is not useful. Typical network configurations are a shopping center, an office building or a local district with fifty houses, two factories and two transformer stations. Such networks have many components. Consequently, straightforward uses of commonly used power electronics component models lead to unmanageable models. Today's complex distribution networks need special models.

To beat complexity it is necessary to develop models that are efficient to simulate. Modeling of solid-state switches (diodes, thyristors and transistors) is a delicate issue. A detailed model includes extreme nonlinearities, which make the model time-consuming to simulate. A simulator with proper discontinuity handling as OmSim can simulate a model with idealized switching elements up to ten times faster.

It is also necessary to work with aggregated models. It would be very useful to have tools that can take a component based model of a part of a network and make a simplified aggregated model. The big question is then how to make the aggregation. One difficulty is that a network includes non-linear components. We are developing a new efficient approach to static simulation and calculation of harmonics. Current results are promising.

Applications

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

Robotics

Researchers: Rolf Johansson, Klas Nilsson, and Anders Robertsson

The laboratory for robotics and real-time systems is centered around an ABB Irb-6 robot and an ABB Irb-2000 robot. Hardware interfaces have been developed to create an open system suitable for control experiments. The computer hardware is VME-based with both micro processors and signal processors integrated into an embedded system for hard real-time control. The system is connected to a network with Sun workstations, which are used for program development and control design.

A purpose of the current project is to show how to organize open robot control systems and to verify these ideas by means of experiments. One goal is to permit efficient specification and generation of fast robot motions along a geometric path which requires coordinated adjustment of the individual joint motions. Another aspect of robot motion control is how to to integrate simultaneous control of force and position according to ideas of impedance control in which stability is an important theoretical issue.

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

A NUTEK-sponsored research program *Lund Research Programme in Autonomous Robotics* with cooperation partners from Dept Production and Materials Engineering and Dept Industrial Electrical Engineering and Automation and industrial partners was continued during the year. A major topic in this project is to integrate aspects of control, sensor fusion and application demands.

During this year Klas Nilsson finished his doctoral dissertation entitled *Industrial Robot Programming* (TFRT-1046).

Real-Time Control

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

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

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

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

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

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

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

Industrial robot control systems are used as a typical demanding real-time application. We have a well proven experimental platform including two ABB robots controlled from our VME-based computers with Sun workstations being used as host computers. This means that the real-time research is well integrated with the robotics research. During 1996 Klas Nilsson finished his PhD thesis on experimental, open robot programming platforms. During the last half of 1996 he has worked part time for ABB Robotics.

During the spring 1996 Johan Eker visited Carnegie Mellon University for two months. He worked together for Lui Sha at the Software Engineering Institute with implementation of fault-tolerant real-time systems. An activity that has close relations to real-time control is the work we are doing on graphical Petri net and Grafcet based languages for sequential supervisory control applications. The platform for this work is G2, a commercial object-oriented environment for real-time applications. We have developed Grafchart, a toolbox that combines real-time expert system techniques with Grafcet. This is a commercial product that currently is being applied for supervisory control in a US oil refinery and for the automation of flexible machining cells in Spain. Grafchart is currently being extended in different object-oriented directions.

High-Level Grafcet for Supervisory Sequential Control

Researchers: Charlotta Johnsson and Karl-Erik Årzén

Sequential Control is extremely important in industry both for continuous, discrete, and batch processes. It is needed both at the direct control level and for supervisory control applications.

During the last years Grafcet, or SFC (Sequential Function Charts), has emerged as an international standard for direct level sequential control, through the standards IEC 848 and IEC 1131-3. Grafcet, which is a graphical programming language has been very well accepted in industry. However, today there is also an industrial need of a graphical programming language suited for sequential control at all control levels.

Grafcet has its roots in Petri Nets. In parallel to the development of Grafcet, High-Level Petri Nets have been developed from ordinary Petri Nets. High-Level Petri Nets combine the expression power of high-level programming languages with the formal specification language properties of Petri Nets while preserving the user-friendly graphical representation. The goal of this project is to develop Grafcet into High-Level Grafcet and thereby make it amenable also to supervisory control applications.

The work is based on Grafchart, a Grafcet toolbox developed at the department since 1991. The toolbox is implemented in G2. It has already been used in industry with great success. High-Level Grafchart is an extension to Grafchart that is currently under implementation. Grafchart is extended with object-oriented programming languages constructs and ideas from High-Level Petri Nets. The new features in High-Level Grafchart, compared with Grafcet, are procedure steps and process steps, parameterization, methods and message passing, object token and multi-dimensional charts.

This project focuses especially on batch control applications. In this context it is investigated how High-Level Grafchart can be used for recipe representation according to the new standard, ISA-S88.01, for batch control. An on-line simulator of a multi-purpose, multi-path batch-cell has been developed and implemented in G2, see Figure 5.2, and is used as a test case.

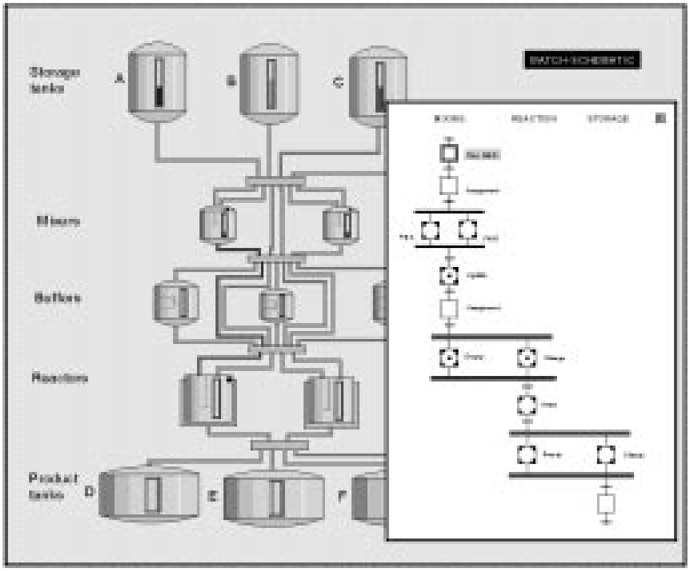


Figure 5.2 Batch Process with Recipe

This research project is founded by NUTEK under the REGINA programme. The project has an industrial steering- and reference-committee consisting of members from Alfa-Laval Automation, ABB Industrial Systems, Astra, Kabi Pharmacia and van der Bergh Foods.

During the fall of 1996, information models for batch plants have been studied and a prototype for combined control and information modeling has been developed. An extended version of the batch scenario was used as a test case. This work was done in cooperation with NUST, Trondheim, Norway.

Rolling Mill Control

Researchers: Lars Malcolm Pedersen and Björn Wittenmark

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

The project has resulted in models for different subprocesses of the rolling process. The models are obtained through a combination of physical model-building and system identifications. The models are based on data collected at the plant. The data are quite unique and have given good insights in how to model the total process. Multivariable controllers based on feedback linearization and eigenspace design have been derived and tested in simulations. The project has resulted in the licentiate thesis Pedersen (1995).

Timing Problems in Real-Time Systems

Researchers: Bo Bernhardsson, Johan Nilsson, and Björn Wittenmark

This is a subproject within the DICOSMOS project, (Distributed Control of Safety Critical Mechanical Systems). DICOSMOS is a cooperation between Department of Computer Engineering, CTH, Department of Mechanical Elements, KTH, and Department of Automatic Control, LTH.

The work in Lund has focused on analysis and design of control systems with communication delays. The results are presented in the licentiate thesis by Nilsson 1996 and in three conference articles. Methods for analysis of stability and performance properties have been developed. A new optimal control scheme has been suggested and analyzed. The new scheme uses so called “time-stamping” of control and measurement messages. The optimal controller has been shown to have the separation property. We have also shown how to use the frame-work of so called jump linear systems to analyze random network delays.

Network delays, or network transfer times, have different characteristics depending on the network hardware and software. To analyze control systems with network delays in the loop we have to model these. Three models of different complexity have been studied. The network models are:

- Constant delay
- Random delay, which is independent from transfer to transfer
- Random delay, with probability distributions governed by a Markov chain

To design a controller for a distributed digital control system it is important to know how to analyze such systems. In standard computer control theory it is assumed that the closed loop system is time-invariant. In a system with varying delays this is not true. In the work it is shown how to analyze linear controllers where the network delays are described by one of the three developed network models above.

The Linear Quadratic Gaussian (LQG) optimal controller has been developed in the case of random delays that are independent from transfer to transfer. The derived controller uses knowledge of old time delays. These can be calculated using "time-stamping" of messages in the network. The solution to the LQG-problem was found by combining an LQ-controller with a Kalman filter. It was shown that a separation principle holds, design of state feedback and state estimator can be done independently.

The developed theory has been tested in small examples. Controllers from the literature have been compared with the developed synthesis method. It is found that the developed control algorithm increases stability and performance of the control system.

Fuzzy Control

Researchers: Karl-Erik Årzén and Mikael Johansson

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

The research at the department covers both the theory and practice of fuzzy control. One of the more important areas is analysis of fuzzy

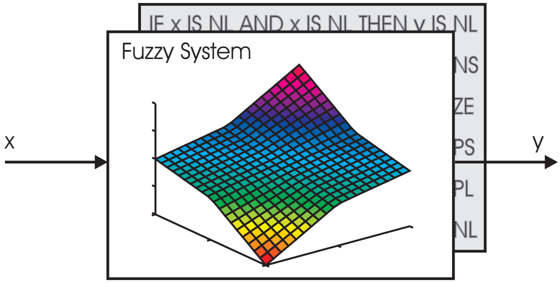


Figure 5.3 Two views of fuzzy control.

controllers which is motivated by the need to understand how fuzzy controllers work. The current work is focused on viewing fuzzy control as a nonlinear interpolation method.

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

The theoretical work in the project has been focused on stability and performance analysis of fuzzy control systems. With the basic observation that many fuzzy control systems have piecewise linear dynamics, analysis methods for such systems have been developed. The methods use piecewise quadratic Lyapunov functions that can be computed using convex optimization techniques. The method appears to have a strong potential for analysis of a wide class of nonlinear systems.

FAMIMO: The department is a partner of the Esprit Long Term Research Project FAMIMO (Fuzzy Algorithms for the Control of Multi-Input Multi-Output Processes). The three year project started in December 1996. The project has five partners and is organized along two industrial benchmarks: a car engine and a fermentation process.

Each partner will apply their favorite design method. The approach that will be use by Lund is based on hybrid and heterogeneous control using fuzzy logic as an interpolation method.

Biomedical Modeling and Control

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

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

The work is supported by the Swedish Medical Research Council (MFR) and the Faculty of Medicine, Lund University. During this year two doctoral dissertations were finished within the project. Hannes Petersen completed his thesis *The Inner Ear and Postural Control in Man* (MERL–1039) and Mikael Karlberg finished *The Neck and Human Balance—A Clinical and Experimental Approach to 'Cervical Vertigo'* (MERL–1040). Dr. Karlberg was awarded the Crafoord Prize for best doctoral dissertation at the faculty of Medicine at Lund University. Rolf Johansson was awarded the 1995 biomedical engineering prize (the Ebeling Prize) of the Swedish Society of Medicine for work within this project.

Control of Biotechnology Processes

Researchers: Mats Åkesson and Per Hagander in cooperation with Jan Peter Axelsson (Pharmacia & Upjohn) and Olle Holst (Department of Biotechnology, Lund University)

In our collaboration with the Department of Biotechnology preliminary experiments are performed with genetically modified *E. coli*. It is found important to design good strategies for the substrate-dosage control in order to achieve reproducible cultivations with high cell densities and high productivity. The growth rate is then substrate-limited to avoid by-product formation and oxygen limitation. As a test system we work with the production of an antibody-binding protein, Protein L.

Work also started in May 1996 on a new contract with Pharmacia & Upjohn, Process R&D, on multivariable control of genetically engineered *E. coli*.

Motion Control

Researchers: Karl Johan Åström, Mattias Grundelius, and Tore Hägglund

Motion control systems are common elements in manufacturing systems. They have a significant influence on quality and production capacity. Traditionally, motion control problems were solved with pure mechanical devices, but there are now many interesting alternatives that combine mechanical designs with different forms of motors and control systems. Such systems are typical cases where trade-off of control and process design is very important.

This Project is funded by NUTEK under the REGINA program. It is performed in close collaboration with Tetra Pak AB.

In the initial phase of the project, the focus is on indexing of packages containing liquid. All packages in the machine follows the same acceleration profile, each package is moved (indexed) several times in the machine. Between the filling station and the sealing station the package is indexed 3 to 5 times. The aim is to find the acceleration profile that minimize the indexing time with a maximum allowed slosh. This can be solved using Optimal Control with state space constraints.

The Knocker—Stiction Compensation in Control Valves

Researcher: Tore Hägglund

Too high friction in control valves results in stick-slip motion. This problem forms the largest source of process variability in the process industry. In an earlier project, a method to detect the oscillations caused by too high stiction has been developed. The project has proceeded with the development of a new procedure to compensate for stiction.

The new procedure, called the Knocker, improves control-loop performance during stick-slip motion by adding small pulses to the controller output.

During 1995 and 1996, the method has been tested in industry. These field tests have shown that the Knocker manages to reduce the variations in the measurement signals during stick-slip motion significantly compared to conventional control. The method is patent pending.

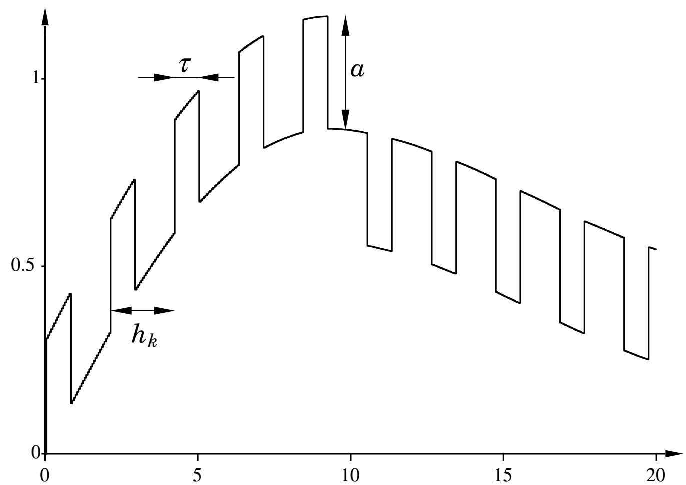


Figure 5.4 The control signal obtained using the knocker.

Collaboration

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

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

Funding

Lund University provides partial support for graduate students. The majority of our research is, however, externally funded from governmental agencies and industry. For the period July 1, 1995, to December 31, 1996, we have had the following contracts:

- TFR – Block grant
- TFR – Adaptive control
- TFR – Computer investments
- NUTEK – Modelling and simulation of complex systems
- NUTEK – Motion control
- NUTEK – Autonomous control
- NUTEK – Heterogeneous systems
- NUTEK – Real-time systems
- NUTEK – Safety-critical systems
- NUTEK – Grafcet
- Governmental funding for research collaboration with Caltech
- ITM – Fuzzy control

- ELFORSK – Modeling of electric power and distribution networks and components
- Sydkraft – Modeling and control of energy processes
- Pharmacia & Upjohn – Multivariable control of genetically engineered *E. coli*.

The Block grant from TFR is long range and some of the NUTEK projects are also long range. Several projects do, however, have a duration of only two years. To match these with the duration of a PhD, which is much longer, we have an internal research planning which is much more long range and we are careful to bid on projects that fit our long range research plan. This has proven an effective way to match short-term funding to long-term planning.

We have also been engaged in the following European projects:

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

6. Research-Staff Activities

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

Mats Åkesson

MSc, graduate student since 1994. During 1995/1996 he has been working on integrated control and diagnosis. Since May 1996 he is working together with Per Hagander on multivariable control of genetically engineered *E. Coli* on a contract with Pharmacia & Upjohn, Process R&D.

Lennart Andersson

MSc, graduate student since 1993. He is interested in modeling and identification of dynamical systems. Current research is modeling of uncertain systems. During fall 1995 he visited Caltech for 3 months as part of the research exchange between Caltech and the Department of Automatic Control in Lund. During this stay he worked with Carolyn Beck and Richard Murray.

Karl-Erik Årzén

Research associate, PhD (1987). Joined the department in 1981. His research interests are Petri Nets and Grafcet, monitoring and diagnosis, fuzzy control, real-time systems and real-time applications of Artificial Intelligence.

Årzén is the project leader for the NUTEK project "High-Level Grafcet for supervisory sequential control," for the ITM project "Fuzzy Control" and for the TFR project "Integrated Control and Diagnosis." He is also responsible for the course Real-Time Systems in the engineering program.

Karl Johan Åström

Professor and head of the department since 1965. His research interests are stochastic control, system identification, adaptive control, computer control, and computer-aided control engineering. He participates in many research projects at the department. He is also responsible for the course Adaptive Control in the engineering program.

In April 1996 he was a Russel Severance Springer Visiting Professor at the department of Mechanical Engineering at University of California, Berkeley.

Bo Bernhardsson

Research associate, PhD. Joined the department in 1987 and took his PhD in 1992. After that he spent 8 months as a post-doc at IMA, University of Minnesota. Interested in system theory, robust control and control applications. During 1995-96 he supervised PhD students in projects on “Control of Hybrid Systems,” “Timing Problems in Real-Time Systems,” and “Modeling of Harmonics in Electrical Power Networks.”

Jonas Eborn

MSc, Graduate Student since 1995. Interested in computer aided control engineering, physical system modeling and numerical analysis. He is working in the NUTEK programme “Complex Technical Systems” and is also involved in the collaboration with Sydkraft AB.

Johan Eker

MSc, graduate student since January 1995. Main research areas are real-time control theory and fault-tolerant control software. Has worked on the development of the Pålsjö environment, a tool for implementation of control systems. This work was done together with Anders Blomdell.

During spring 1996 he visited Bruce Krogh and Lui Sha at Carnegie Mellon University in Pittsburgh, USA, for 1.5 month and worked there with fault-tolerant evolvable real-time software at the Software Engineering Institute.

Mattias Grundelius

MSc, graduate student since January 1996. He is interested in Control in general and works with optimal control in packaging machines in a collaboration with Tetra Pak. He has also been working with laboratory development in the the courses Process Control and Real-time Systems.

Magnus Gäfvert

MSc, graduate student since July 1996. Interested in hybrid control and implementation of control systems. Currently working on modeling and analysis of systems with friction, and on friction compensation in servo systems.

Per Hagander

Associate professor, PhD (1973). Has been with the department since 1968 and is the Director of Studies at the department. He works with linear system theory and with applications in biotechnology and medicine. He is responsible for the course Automatic Process Control in the engineering program.

During 95/96 he continued the work with Anders Hansson on the Minimum Upcrossing controllers and singular LQG-problems. Anders Hansson is now postdoc at Stanford University. During the spring a contract was signed with Pharmacia & Upjohn, Process R&D, on multivariable control of genetically engineered *E. coli*. Here Per Hagander works together with Mats Åkesson.

Tore Hägglund

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

Hägglund participates in the NUTEK project "Autonomous Control." Main research activities during the academic year have been design of PID controllers and dead-time compensators. Industrial field tests of a new compensator for static friction in control valves has also been performed.

Karl Henrik Johansson

MSc, graduate student since 1992. He is working in a project on multi-loop control systems. As part of this project, Karl Henrik studies performance limitations in multi-loop systems, develops automatic methods for multivariable control tuning, investigates properties of relay feedback systems, and works on multivariable control of a deaerator process for Tetra Pak Processing Systems AB. The research on relay feedback systems resulted in the Young Author Prize at the IFAC World Congress 1996.

Mikael Johansson

Msc, graduate student since 1994. His research interests include nonlinear control, modeling and identification. He is working in the ITM project on "Design and Tuning of Fuzzy Controllers based on Nonlinear Control Theory."

Rolf Johansson

Associate professor, PhD (1983), MD (1986). Active at the department since 1979. Rolf Johansson's research interests are in system identification and in robotics and nonlinear systems. He is coordinating director for a NUTEK-sponsored research program "Lund Research Programme in Autonomous Robotics" with cooperation partners from Dept Production and Materials Engineering and Dept Industrial Electrical Engineering and Automation and industrial partners. He is also responsible for the two courses System Identification and Nonlinear Control and Servo Systems in the engineering program.

Together with Dr. Måns Magnusson he leads research at the Vestibular Laboratory, Dept. Otorhinolaryngology, Lund University Hospital.

Charlotta Johnsson

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

Ulf Jönsson

PhD. Joined the department in 1990 and finished his PhD in November 1996. His research has been directed towards the development of methods for robustness analysis of nonlinear and uncertain systems. He has been responsible for the organization of the two latest Lund-Lyngby days on Control; October 26, 1995 (in Lyngby), together with Erik Beran at DTU in Denmark, and May 10, 1996 (in Lund), together with Uffe H. Thygesen at DTU. From January 1997 Ulf Jönsson is visiting California Institute of Technology.

Jörgen Malmborg

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

Sven Erik Mattsson

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

Mattsson is the project leader for the NUTEK project “Modeling and Simulation of Complex Systems” which is a part of NUTEK’s research program “Complex Systems.” He is also the project leader for the project “Modeling and Control of Energy Process” which is a collaboration project with Sydkraft Konsult AB. It is founded by Sydkraft AB. He has developed and given a new graduate course “Object-Oriented Modeling of Hybrid Technical Systems.”

Erik Möllerstedt

MSc, graduate student since 1994. His research interests are analysis, modeling, simulation and control of non-linear systems. He is currently working in the ELEKTRA project “Modeling of Electricity Distribution Networks and Components” sponsored by Elforsk and NUTEK.

Bernt Nilsson

Research Associate, PhD (1993). He has been at the department since 1985. His major interest is in process modeling, simulation and control. During 1995 Nilsson continued the work on the K2 model database for modeling of thermal power plants. He is also interested in batch processing and control.

During the spring of 1996 Nilsson gave a PhD course in Simulation of Process Systems. Nilsson held a series of three lectures in the PhD course Object-Oriented Modeling of Hybrid Technical Systems at the department. He also held two lectures in the PhD course Object-Oriented Modeling and Computer Algebra at Department of Computer Science at Linköping Institute of Tecnology.

Johan Nilsson

Lic Tech in May 1996, graduate student since 1992. His research interests concerns both theory and applications. The major research area is in the field of timing problems in real-time systems.

Klas Nilsson

PhD, defended his PhD thesis “Industrial Robot Programming” in May 1996. Klas came to the department from ABB Robotics in 1988. The main research interests are robot control and real-time systems, but he also likes to work with systems and tools for experimental verification. He is involved in the NUTEK projects “Lund Research Programme in Autonomous Robotics” and “Application Specific Real-Time Systems”. In the near future he will continue to work on implementation of robot control systems.

Martin Öhman

MSc, graduate student since January 1996. He is interested in modeling and model reduction. He is also working with PLC programming standard IEC 1131.

Henrik Olsson

PhD, defended his dissertation in May 1996. His main research interest is in nonlinear control systems and his work includes modeling and analysis of systems with friction as well as friction compensation in servo systems. He has been working in the TFR-project “Robust and Nonlinear Adaptive Control”. From October 1996 he was employed at Daimler-Benz AG in Berlin.

Hélène Panagopolous

MSc, graduate student since August 1995. Her research interests include PID control and process control. She is currently working on the design of PID controllers.

Lars Malcolm Pedersen

Lic Tech in September 1995. Pedersen joined the department in 1992 as an employee of the Danish Steel Works Ltd, working both at DDS and with us. His main research interests are process modeling, system identification, and applying advanced theory to real world processes. He has been working on the project “Improvement of Rolling Mill Control System.”

Anders Rantzer

Research associate, PhD (KTH 1991). Joined the department in 1993 after a postdoc position at IMA, University of Minnesota. Research interests are in modeling, analysis and design of uncertain and nonlinear systems.

This year he supervised students in the projects “Control of Uncertain Systems”, “Modeling with Quantified Accuracy”, “Multi-Loop Control Systems” and “Fuzzy Control”.

Anders Robertsson

MSc, graduate student since 1993. His research interests are in nonlinear control and robotics and he is working in the NUTEK project “Lund Research Programme in Autonomous Robotics.” In June 1996 he spent two weeks at University of Twente, The Netherlands.

Anders Wallén

MSc, graduate student since 1991. His main research interests are control loop supervision and software design of control systems. He is working in the NUTEK project "Autonomous Control."

Björn Wittenmark

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

7. Looking Back: Automatic Tuning

Following the tradition from previous annual reports, we will discuss one of our earlier research projects. This time we will describe the project on automatic tuning of PID controllers. The project started as a minor effort in our large adaptive control projects. It developed into a major project that has had significant influence on future research. It has also had a large industrial impact. In this respect it illustrates how we can deal with the "third mission" (see the beginning of Chapter 5).

Background

During the seventies and the beginning of the eighties, adaptive control was by far the largest research topic in automatic control at many universities. The theory was developed and industrial field tests demonstrated the benefits of the technique. The controllers were, however, rather complicated and required both time and skilled engineers to be operated properly. This limited the industrial impact of the technique.

During a project meeting in the fall 1980, some of our industrial partners raised the question whether it was possible to use the adaptive technique to tune standard PID controllers that are used in process control. This question is quite natural since the majority of control problems ($> 90\%$) are solved by PID controllers. At this time it was, however, quite unfashionable at universities to consider such mundane devices as PID controllers.

We first tested the obvious solution to use the adaptive controller as a tuning aid. It turned out that this was a bad idea, since the adaptive controllers require too much apriori knowledge. Most engineers consider the task to provide an adaptive controller with sampling periods, model orders etc to be more difficult than to provide

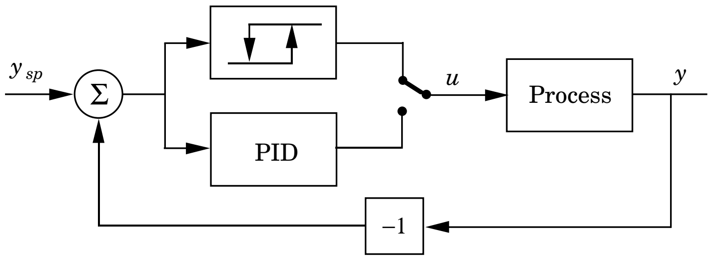


Figure 7.1 The relay auto-tuner. In the tuning mode the process is connected to relay feedback.

the PID controller with its standard parameters. Therefore, we started to look for special methods. This resulted in the relay autotuner.

The Relay Autotuner

It is not necessary to know the process dynamics in detail to tune a PID controller. It is sufficient to know a few parameters such as process gain, dead time, and dominating time constant in the time domain, or the ultimate gain and the ultimate frequency in the frequency domain. What is more important, is to have a procedure that is fast, robust, and easy to use.

The early work on self-oscillating adaptive systems performed by Honeywell in the late 1950s was a source of inspiration for the relay autotuner. In these systems, a relay is a crucial component used to automatically adjust the loop gain so that a gain margin of two is maintained. We analyzed these systems in PhD courses on adaptive control in the early 1980s.

In the relay autotuner, the ultimate frequency and the ultimate gain of the process are obtained in the following way. During the tuning phase, the PID algorithm is replaced by a function that can be described as relay with hysteresis. See Figure 7.1. The relay causes the control loop to oscillate with a stable limit cycle. After a few periods of oscillation, the frequency and the amplitude are determined. The frequency of the limit cycle is close to the ultimate frequency. The ultimate gain can be obtained from the relation between the amplitudes of the process input and output, respectively. Controller parameters are then calculated based on this process information, and the PID algorithm replaces the relay function.

Transfer to Industry

After the first investigations of the relay autotuner, we realized that it could be a good idea to apply for a patent of the method. During this time, there were lots of criticism from industry about the relatively small number of university patents. We got support from the Swedish Board for Technical Development (STU) and applied for a patent in August 1981. A Swedish patent was granted to T. Hägglund and K. J. Åström in July 1983 for the relay autotuner. Patents were later granted also in Denmark, Norway, Finland, USA, and Canada.

During these first years of the eighties, we also contacted potential industrial partners. NAF Controls (later SattControl Instruments, now Alfa Laval Automation) showed the greatest interest. We transferred all the rights to them in August 1982. This was the starting point for a very active collaboration.

In the summer 1982, we had a simple prototype running on an Apple IIe computer. In November that year, this prototype was tested at a sugar refinery (now Danisco Sugar) in Arlöv. These tests were very promising, although they showed that quite a lot of work remained to be done in order to obtain a robust autotuner.

We convinced NAF Controls about the importance of having a competent receiver of the technique inside their organization. Therefore, they employed one of our former students, Lars Bååth. Together with him, we started the exciting project of turning a good idea into a useful industrial product. This work consisted in simulations and lots of industrial field tests.

The size of this company, around 100 persons, turned out to be very efficient for development projects like this one. It was easy to get feedback and opinions from not only the development department, but also from production, marketing, maintenance and application departments.

The first industrial product was released in 1984. It was a small instrument system named SDM-20. At that time, automatic tuning was a new concept that the customers had not heard about before. Some of them were very eager to test and use it, whereas others were sceptic about having a procedure ”making tests on its own”. However, the benefits of the technique were soon realized and it is now used routinely.

In 1985 Tore Hägglund left for SattControl, where he worked until 1989. Development of controllers in the ECA family with autotuning, gainscheduling, and adaptation of feedback and feedforward gains were his main responsibility. The work was carried out in the Lund Science Park whose proximity led to to an intensified collaboration between our department and SattControl.

In 1986, SattControl released the single-station controller series ECA with the relay autotuner implemented. In these controllers, the relay autotuner can be activated simply by pressing a ”tuning button”. See Figure 7.2. Today Alfa Laval Automation also produces OEM products with automaic tuning for companies such as Fisher-Rosemount and Foxboro-Eckardt. About 30,000 units have been manufactured.

The experience of the use of the relay autotuner shows two main advantages. First of all, the autotuner provides controller settings that in most cases are significantly better than those obtained from manual tuning. It is, for example, often only those loops that are tuned automatically where one find the derivative part in operation. The second advantage is the time saving. Tuning control loops with the relay autotuner is performed in a much shorter time than with manual tuning.

The relay autotuner has also provided the possibility to use other advanced control concepts in an industrial environment. Already the first implementations of the relay autotuner were equipped with gain scheduling, where the gain schedule was obtained automatically using the relay autotuner. Without automatic tuning facilities, gain scheduling would not have been used in process control as much as it is today.

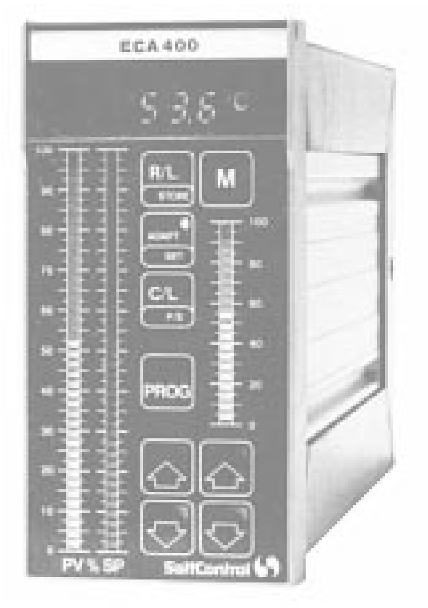


Figure 7.2 The Alfa Laval Automation ECA400 controller.

The autotuner also provides a possibility to automatically initialize adaptive controllers. Alfa Laval Automation released an adaptive PID controller in 1989 that can be set in operation automatically based on the relay autotuner. In later years, the autotuner has also been used to initialize supervisory functions for valve diagnosis.

Research Impact

The work on relay autotuners for PID controllers generated many theoretical problems that were explored in PhD theses. The dissertations by Karl-Erik Årzén, Lars Rundqwist, Ulf Holmberg, Michael Lundh, and Per Persson are all related to this project. There are also numerous master thesis projects made in this area. Some interesting theoretical questions that have been treated are: For which systems will there be a stable oscillation under relay feedback? Will there be a unique amplitude and frequency? These questions are now pursued by several PhD students. It is also interesting to observe that research on PID control and automatic tuning have been taken up by many groups world wide.

PID Control

The work on the relay autotuner has stimulated another line of research, namely PID control. The PID controller is by far the most common control algorithm. This control algorithm is also used in the autotuner. When working on the autotuner it became clear that, even if much work on PID control was done in the 1940s and the 1950s, good design methods are still lacking. Much of the early work focused on simple techniques based on crude models. Much better results can be obtained by using the computational tools available today. Our current experiences have been summarized in the book by Åström and Hägglund: *PID Controllers: Theory, Design and Tuning*, published by the Instrument Society of America (ISA), 1988, second edition 1995. There is, however, much more to be done. Advances in this field can have significant industrial impact because of the wide-spread use of PID control. Research into design methods for PID control are therefore continuing.

The relay autotuner has also been an important tool in our later projects on expert control and autonomous control. The autotuner is a key component in these systems, since it is used in the very first step to obtain crucial information about the process dynamics, perhaps totally unknown.

What We Learned

The relay autotuner project has given us lots of experience, where the industrial contacts are the most important.

At the beginning of the project, we realized that there was a difference between our view and the industrial users' view on the final product. A researcher often looks for the best solutions in terms of optimal behaviour, whereas the user is satisfied with something that is ”good enough.” Far more important is to have something that is robust and reliable. Furthermore, the end users will not use a product unless they have a basic understanding of how it works. This is another reason for not making products more complicated than necessary.

We have experienced the importance of having competence inside the organization of the industrial partner. Enthusiasm is not enough. This is important not only for the development, but also for the maintenance and marketing. An end user will not use a product if the vendor does not understand how it works.

Another experience is, that in order to have a good idea implemented and used in industrial projects, it is not sufficient to just provide the ideas. It is necessary to follow the development project *to the end*. The final stages of the development project are often very interesting and sources for new ideas and further research. Participation in field tests is also a very good learning experience.

8. Dissertations

Three PhD dissertations and two Lic Tech theses were defended during the period July 1, 1995 – December 31, 1996. The abstracts are presented here in chronological order.

Multivariable Thickness Control of a Hot Rolling Mill

Lars Malcolm Pedersen
Lic Tech dissertation, September 22, 1995

The purpose of this report is to design a thickness controller for a hot rolling mill. The thickness control problem is difficult and small improvements make large savings possible. It is therefore relevant to use advanced control strategies for controlling the plate thickness.

In the report a short introduction to the thickness control problem, and a description of how thickness control is done today, is first given. Then a physical model for the hot rolling process is developed, measurements are collected, and the parameters of this model are found using system identification. The model is used for finding a control strategy and to design a controller for the plate thickness. As control methods feedback linearization and eigenspace design are used. The performance of the controller is investigated using computer simulations. Furthermore, the stability is analyzed and the effects of the present parameter variations is also investigated.

The main effort has been spent on developing the model for the rolling mill and identifying the parameters of this model. Modeling is a recursive procedure and after the first iteration several changes of the model were necessary to obtain proper results. Since there are many things to vary in the model and in the way of doing the system identification, it is a complicated procedure to find the right set-up.

It should be recognized that besides the control strategy many other things have been gained from the work with the problem. The knowledge of the nature of the rolling process, for instance, have increased significantly in connection with the modeling and system identification.

Analysis and Design of Real-Time Systems with Random Delays

Johan Nilsson
Lic Tech dissertation, May 8, 1996.

Control loops that are closed over a communication network get more and more common. A problem with such systems is that the transfer delays will be varying with different characteristics depending on the network hardware and software. To analyze control systems with network delays in the loop we have to model these. The network delay is typically varying due to varying network load, scheduling policies in the network and the nodes, and due to network failures. Three network models of different complexity are studied:

- Constant delay
- Random delay, which is independent from transfer to transfer
- Random delay, with probability distributions governed by a Markov chain

To design a controller for a distributed digital control system it is important to know how to analyze such systems. In standard computer control theory it is assumed that the closed-loop system is time-invariant. In a system with varying delays this is not true. In the work it is shown how to analyze stability and expected performance of linear controllers where the network delays are described by one of the three developed network models above. Methods to evaluate a quadratic cost function are developed. Through the same analysis we find criteria for mean square stability of the closed loop for the different network models.

The Linear Quadratic Gaussian (LQG) optimal controller is developed in the case of random delays that are independent from transfer to transfer. The derived controller uses knowledge of old time delays. These can be calculated using "time-stamping" of messages in the network. "Time-stamping" means that every transfered signal is marked with the time of generation. The receiving node can then calculate how long the transfer delay was by comparing the time-stamp with the node's internal clock.

Control Systems with Friction

Henrik Olsson
PhD dissertation, May 24, 1996

Opponent: Prof Bernard Friedland, New Jersey Institute of Technology, USA. Committee: Prof Mille Millnert, Linköping Univ, Sweden; Prof Mogens Blanke, Aalborg University, Denmark; Dr Torgny Brogård, ABB Robotics, Sweden.

Friction-related problems are frequently encountered in control systems. The dissertation treats three aspects of such problems: modeling, analysis, and friction compensation. A new dynamic friction model is presented and investigated. The model is described by a first-order nonlinear differential equation with a reasonable number of parameters, yet it captures most of the experimentally observed friction phenomena. The model is suitable both for simulation purposes and control design.

Analysis of friction-generated limit cycles in control systems is the second topic of the dissertation. A distinction is made between limit cycles with and without periods of sticking. Oscillations without sticking where the velocity is zero only for single time instants can be treated as oscillations in relay-feedback systems for which tools are available. These tools are extended to oscillations with sticking where the velocity is kept at zero for a period of time by the friction. The new tools give a procedure for exact computation of the shape and stability of limit cycles caused by friction. The procedure requires the solution of a nonlinear equation system and that the feasibility of the solution is checked. The method is applied to several examples and comparisons are made with describing function analysis.

The dissertation also treats friction compensation based on the new model. A friction force observer is developed which enables model-based friction compensation. The observer can be combined with traditional linear compensators. Stability theorems are given which allow a wide range of controller designs. The compensation scheme is applied to an example where the performance is studied with respect to model errors and disturbances. The resulting control error is thoroughly investigated. It is described how a simple statistical analysis of the error can give information on the success of the friction compensation. Furthermore, the error during zero velocity crossings provides information on how model parameters should be changed.

Industrial Robot Programming

Klas Nilsson
PhD dissertation, May 29, 1996

Opponent: Prof Mark Spong, University of Illinois. Committee: Dr Steve Murphy, ABB Robotics; Prof Peter Johansen, University of Copenhagen; Prof Christer Johansson, Linköping University.

Industrial robots play a key role in manufacturing systems. Robots are distinguished from other types of machinery mainly on the basis of their programmability and ability to be adaptable to different tasks. The use of computer control to achieve desired flexibility implies that software issues for embedded control systems are central for the applicability and utilization of the equipment. The structure of control systems today, however, limits the applicability of robots, thus leaving many human unfriendly operations to be performed manually.

This thesis takes a problem-oriented approach, without enforcing use of formal methods. Considering industrial demands, such as computing efficiency and simple factory-floor operation, a layered system architecture and technical solutions to accomplish it are proposed. A notion of *user views* is introduced as the basis for definition of the layers; the layers support programming on levels ranging from implementation of motor control and up to end-user programming. An experimental platform, built around industrially available robots, has been developed. Specially developed hardware interfaces and reconfigurations of the original (ABB) system permits control and programming even of the low level motion control.

Run-time efficiency within the proposed open and layered system was achieved by a new concept called actions. Actions are pieces of compiled code that, by use of certain compiling and linking techniques, can be passed as parameters between the layers. The required interplay between application specific programs and built-in motion control could therefore be accomplished. A number of case studies and results from ongoing experimental evaluation indicate that the proposed control system principles are very useful also in an industrial context.

Robustness Analysis of Uncertain and Nonlinear Systems

Ulf Jönsson
PhD dissertation, November 1, 1996

Opponent:Professor Munther Dahleh, Massachusetts Institute of Technology. Committee: Prof Anders Lindquist, KTH; Prof Jakob Stoustrup, Technical University of Denmark; Dr Anders Helmersson, Linköping Institute of Technology.

Control design is often done based on simplified models. After design it is necessary to verify that the real closed-loop system behaves well. This is mostly done by experiments and simulations. Theoretical analysis is an important complement to this that can help to verify critical cases.

Structural information about uncertainties, time-variations, nonlinearities, and signals can be described by integral quadratic constraints. The information provided by these constraints can be used to reduce conservatism in analysis of robust stability and robust performance. Several aspects of this method for robustness analysis are treated in the thesis.

It is shown how the Popov criterion can be used in combination with other integral quadratic constraints. A new Popov criterion for systems with slowly time-varying polytopic uncertainty is obtained as a result of this. A corresponding result for systems with parametric uncertainty is also derived.

The robustness analysis is in practice a problem of finding the most appropriate integral quadratic constraint. This can be formulated as a convex but infinite-dimensional optimization problem. The thesis introduces a flexible format for computations over finite-dimensional subspaces. The restricted optimization problem can generally be formulated in terms of linear matrix inequalities.

Duality theory is used to obtain bounds on the computational conservatism. A class of problems is identified for which the dual is particularly attractive.

9. Honors and Awards

Karl Johan Åström became a foreign associate of the US National Academy of Engineering in September 1995.

Karl Johan Åström was awarded the Sigillum Magnum of the University of Bologna, Italy, in 1996.

Karl Johan Åström was given an honoran doctorate from the Royal Institute of Technology in Stockholm on November 13, 1996.

Per Hagander was awarded the position as ”Biträdande professor” at Lund university on October 24, 1995.

Karl Henrik Johansson received the 1996 *Scania Scholarship* for his work on multivariable control systems in May 1996.

Karl Henrik Johansson and **Anders Rantzer** were awarded the Young Author Prize for their paper on relay feedback control at the 13th IFAC World Congress, San Francisco, July 1996.

Rolf Johansson was awarded the 1995 biomedical engineering prize (the Ebeling Prize) of the Swedish Society of Medicine for “distinguished contribution to the study of human balance through application and development of system analysis and robotics.” The prize was presented on Nov 29, 1995, at the annual meeting of the Swedish Society of Medicine.

Johan Nilsson received the 1996 *Scania Scholarship* for his work on analysis of control systems with network-induced delays, May 1996.

10. Personnel and Visitors

Personnel

During this 18 months report period the following persons have been employed at the department. The list shows the *status of December 1996* if nothing else is mentioned.

Professors

Karl Johan Åström
Per Hagander (biträdande)
Björn Wittenmark

Associate Professors

Tore Hägglund
Rolf Johansson

Research Associates

Karl-Erik Årzén
Bo Bernhardsson
Sven Erik Mattsson
Bernt Nilsson
Klas Nilsson *(graduated May 1996)*
Anders Rantzer

Research Engineers

Leif Andersson
Anders Blomdell
Rolf Braun
Tomas Schönthal

PhD Students

Lennart Andersson
Jonas Eborn
Johan Eker
Mattias Grundelius *(from January 1996)*
Magnus Gäfvert *(from August 1996)*
Karl Henrik Johansson
Mikael Johansson
Charlotta Johnsson
Ulf Jönsson *(graduated November 1996)*
Jörgen Malmborg
Erik Möllerstedt (former Gustafson)
Johan Nilsson
Henrik Olsson *(graduated May 1996, left the department October 1996)*
Hélène Panagopoulos
Anders Robertsson
Anders Wallén
Mats Åkesson
Martin Öhman *(from January 1996)*

Secretaries

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

Temporary Appointments

Helena Haglund *(1 month, Nov–Dec, 1995)*

Visiting Scientists

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

Roberto Girelli *August 1 – September 30, 1995*
Dipartimento di Elettronica e Informazione
Politecnico di Milano, Milano, Italy

Sergio Savaresi *August 18 – September 18, 1995*
Dipartimento di Elettronica e Informazione,
Politecnico di Milano, Milano, Italy

Richard Murray *August 14 – 30, 1995*
California Institute of Technology
Pasadena, California, USA

Li Qiu *August 7 – 13, 1995*
Hong Kong University

Alexander Megretskii *August 2 – 14, 1995*
Iowa State University

Rod Bell *April 1 – June 30, 1995,*
and December 8, 1996 – January 30, 1997
Macquarie University, School of Mathematics and Physics,
New South Wales, Australia

Arjan van der Schaft *January 24 – January 28, 1996*
University of Twente, Dept of Applied Mathematics,
Enschede, The Netherlands

Robert van der Geest *January 1 – February 29*
and August 12–28, 1996
University of Twente, Faculty of Applied Mathematics,
Systems and Control Group, Enschede, The Netherlands

Carsten Scherer *March 24 – March 31, 1996*
Mechanical Engineering Systems and Control Group
Delft University of Technology, Delft, The Netherlands

Erno Keskinen *November 6 – April 30, 1996*
Tampere University of Technology,
Dept of Mechanical Engineering, Tampere, Finland

Carlos Canudas de Wit *May 23 – May 30, 1996*
Laboratoire d'Automatique de Grenoble,
ENSIEG, France

Pascale Bendotti *June 9 – June 16, 1996*
Electricite de France, Direction des Etudes et Recherches,
Chatou, France

Michael Branicky *May 16 – June 27, 1996*
MIT, Lab for Information and Decision Systems,
Cambridge, Massachusetts, USA

Carolyn Beck *January 24 – June 30, 1996*
Dept of Electrical Engineering, California Institute of Technology,
Pasadena, California, USA

C. T. Chou *July 31 – September 6, 1996*
Delft University of Technology, Dept of Electrical Engineering,
Delft, The Netherlands

Michel Verhaegen *July 31 – September 6, 1996*
Delft University of Technology, Dept of Electrical Engineering,
Delft, The Netherlands

Nina Thornhill *August 24 – September 28, 1996*
University College London, Dept of Electronic and Electrical
Engineering, London, UK

Martin Otter *October 1–22, 1996*
DLR Oberpfaffenhofen,
Institut für Robotik und Systemdynamik, Wessling, Germany

Jo Simensen *August 12 – November 8, 1996*
The Norwegian Univ of Science and Technology,
Dept of Engineering Cybernetics, Trondheim, Norway

Hector Sussman *November 4–15, 1996*
Rutgers University, Dept of Mathematics,
New Brunswick, New Jersey, USA

James Sørlie *September 2, 1996 – 30 April 1997*
Royal Institute of Technology, S3—Automatic Control,
Stockholm, Sweden

Pericles Barros *September 16, 1996 – February 15, 1997*
Universidade Federal da Paraiba, Departamento de Enghenharia Elétrica, Campina Grande, Brazil

Victor Terpstra *December 1–14, 1996*
Delft University of Technology, Faculty of Electrical Engineering, Control Laboratory, Delft, The Netherlands

Visiting Students

The following foreign students have stayed with the department and and followed the courses. Many of them have made their master's theses. Students marked with "(E)" are from the ERASMUS program.

Costas Konstantinos Yalirakis (E) *May 1 – 31 August, 1995*
Imperial College of Science, Technology and Medicine, London, UK

Alexander Kennedy Urquhart (E) *May 1 – 31 August, 1995*
Imperial College of Science, Technology and Medicine, London, UK

Maria-Christina Laiou (E) *May 1 – 31 August, 1995*
Imperial College of Science, Technology and Medicine, London, UK

Lourdes Penalver *June 1 – July 31, 1995*
Departamento de Ingenieria de Sistemas Computadores y Automatica, Universidad Politecnica de Valencia, Spain

Richard McAleer (E) *June 6 – September 21, 1995*
Dept of Electronics & Electrical Engineering, Glasgow University, UK

Luis Antonio Rosa Sobral *October 19, 1994 – July 10, 1995*
Department of Electrical Enginering,
Faculdade de Ciencias e Tecnologia da Universidade de Coimbra, Coimbra, Portugal

Jan Peter Meeuwse (E) *September 1, 1994 – July 20, 1995*
Eindhoven University of Technology, Department of Mechanical Engineering, Eindhoven, The Netherlands

David Angeli *September 25, 1995 – February 23, 1996*
Dipartimento di Sistemi e Informatica, Universita di Firenze, Firenze, Italy

Bart Hendriks (E) *October 2, 1995 – March 31, 1996*
Delft University of Technology, Faculty of Electrical Engineering, Delft, The Netherlands

Nadia Pariset (E) *March 4 – June 30, 1996*
Département Automatique, Ecole des Mines de Nantes, France

Rui Pedro Pinto de Carvalho e Paiva (E) *January 17 – June 30, 1996*
Universidade de Coimbra, Departamento de Engenharia Informatica, Coimbra, Portugal

Michelangelo Calabresi (E) *January 17 – July 17, 1996*
Universita di Roma “La Sapienza”,
Departimento di Informatica e Sistemistica, Rome, Italy

Egil Overaa (E) *June 18 – September 29, 1996*
Imperial College of Science, Technology and Medicine,
Dept of Electrical and Electronic Engineering,
London, UK

Cesar Mendoza-Serrano (E) *June 1 – September 30, 1996*
Imperial College of Science, Technology and Medicine,
Dept of Electrical and Electronic Engineering, London, UK

Sabina Brufani (E) *June 18, 1996 – February 21, 1997*
Universita di Roma “La Sapienza”,
Departimento di Informatica e Sistemistica, Rome, Italy

Berndt Trageser (E) *September 16, 1996 – December 16, 1996*
Technische Hochschule, Darmstadt

José Luis Guerra da Rocha Nunes (E) *October 2, 1996 – June 30, 1997*
Univ of Coimbra, Informatic Department,
Coimbra, Portugal

11. Publications and Conference Contributions

One book has been finished during this report period, 11 book contributions have been published, 19 journal papers, 72 conference contributions, and 7 conference abstracts.

Books and Proceedings

Åström, Karl Johan, and Björn Wittenmark: *Computer-Controlled Systems*. Prentice Hall, third edition, 1997.

Book Contributions

Åström, Karl Johan: “Adaptive control.” In Masten, Ed., *Modern Control Systems*, pp. 347–374. IEEE, Piscataway, New Jersey, 1995.

Åström, Karl Johan: “Computer-aided control engineering.” In Masten, Ed., *Modern Control Systems*, pp. 447–480. IEEE, Piscataway, New Jersey, 1995.

Åström, Karl Johan: “Adaptive control: General methodology.” In Arbib, Ed., *The Handbook of Brain Theory and Neural Networks*, pp. 66–73. MIT Press, 1995.

Åström, Karl Johan: “Automatic control: A perspective.” In Bonivento *et al.*, Eds., *Colloquium on Automatic Control*, Lecture Notes in Control and Information Sciences 215, pp. 1–26. Springer, 1996.

Åström, Karl Johan: “Fundamental limitations of control system performance.” In Paulraj *et al.*, Eds., *Mathematical Engineering: A Kailath Festschrift*. Kluwer Academic Publishers, 1996.

Åström, Karl Johan, and Tore Hägglund: "PID control." In Levine, Ed., *The Control Handbook*, pp. 198–209. CRC Press and IEEE Press, 1996.

Bernhardsson, Bo, Anders Rantzer, and L. Qiu: "A summary on the real stability radius and real perturbation values." In Jeltsch and Mansour, Eds., *Stability Theory—Hurwitz Centenary Conference, Ascona 1995*, vol. 121 of *ISNM*, Basel, Switzerland, 1996. Birkhäuser Verlag.

Hägglund, Tore, and Karl Johan Åström: "Automatic tuning of PID controllers." In Levine, Ed., *The Control Handbook*, pp. 817–826. CRC Press and IEEE Press, 1996.

Johansson, Rolf: *z Transform and Digital Systems*, chapter 101, The Engineering Handbook, pp. 1096–1107. CRC Press, Boca Raton, Florida, 1996.

Kuipers, Benjamin, and Karl Johan Åström: "The composition and validation of heterogeneous control laws." In Murray-Smith and Johansen, Eds., *Multiple Model Approaches to Nonlinear Modelling and Control*, London, UK, 1996. Taylor & Francis.

Magnusson, M., Rolf Johansson, and P.-A. Fransson: *Multisensory Control of Posture*, chapter Efforts to Quantify Adaptation in Modeling of Postural Control, pp. 289–293. Plenum Press, New York, 1995.

Journal Papers

Årzén, Karl-Erik: "Integrated control and diagnosis of sequential processes." *Control Engineering Practice*, **4:9**, 1996.

Årzén, Karl-Erik, and Charlotta Johnsson: "Object-oriented SFC and ISA-S88.01 recipes." *ISA Transactions*, **35**, pp. 237–244, 1996.

Åström, Karl Johan: "Adaptive control around 1960." *IEEE Control Systems*, **16:3**, pp. 44–49, 1996.

Brantberg, K., P. A. Fransson, M. Magnusson, Rolf Johansson, and J. Bergenius: "Short vestibulo-ocular reflex time-constant in complete unilateral vestibular lesions." *The American Journal of Otology*, **16:6**, pp. 787–792, November 1995.

Hagander, Per, and Anders Hansson: "Existence of discrete-time LQG-controllers." *System & Control Letters*, **26:4**, pp. 231–238, 1995.

Hägglund, Tore: "A control-loop performance monitor." *Control Engineering Practice*, **3**, pp. 1543–1551, 1995.

Hägglund, Tore: "An industrial dead-time compensating PI controller." *Control Engineering Practice*, **4**, pp. 749–756, 1996.

Hägglund, Tore: "Modern controllers supervise valves automatically." *InTech*, **43:1**, pp. 44–46, 1996.

Holm, M., Rolf Johansson, S. B. Olsson, J. Brandt, and C. Lührs: "A new method for analaysis of atrial activation during chronic atrial fibrillation in man." *IEEE Transactions on Biomedical Engineering*, **43:2**, pp. 198–210, February 1996.

Johansson, Rolf: "Supermartingale analysis of minimum variance adaptive control." *Control-Theory and Advanced Technology (C-TAT)*, **10:4**, pp. 993–1013, 1995.

Jönsson, Ulf, and Anders Rantzer: "Systems with uncertain parameters—time-variations with bounded derivatives." *International Journal of Robust and Nonlinear Control*, **6:9/10**, pp. 969–982, November-December 1996.

Karlberg, M., Rolf Johansson, M. Magnusson, and P. A. Fransson: "Dizziness of suspected cervical origin distinguished by posturographic assessment of human postural dynamics." *Journal of Vestibular Research*, **6:1**, pp. 37–47, 1996.

Kheir, N. A., Karl Johan Åström, D. Auslander, K. C. Cheok, G. F. Franklin, M. Masten, and M. Rabins: "Control systems engineering education." *Automatica*, **32:2**, pp. 147–166, 1996.

Magnusson, M., H. Petersen, S. Harris, and Rolf Johansson: "Postural control and vestibulospinal function in patients selected for cochlear implantation." *British Journal of Audiology*, **29**, pp. 231–236, 1995.

Mattsson, Sven Erik: “Simulation of object-oriented continuous time models.” *Mathematics and Computers in Simulation*, **39**, pp. 513–518, 1995.

Petersen, H., M. Magnusson, Rolf Johansson, M. Åkesson, and P. A. Fransson: “Acoustic cues and postural control.” *Scand. J. Rehab. Med.*, **27**, pp. 99–104, 1995.

Rantzer, Anders: “On the Kalman-Yakubovich-Popov lemma.” *Systems and Control Letters*, **27:5**, 1996.

Rantzer, Anders: “Review of ‘Control of uncertain systems: A linear programming approach’ by Dahleh and Diaz-Bobillo.” *Automatica*, **32:6**, June 1996. Invited paper.

Sagatun, S. I., and Rolf Johansson: “Optimal and adaptive control of underwater vehicles.” *Advanced Robotics*, **10:3**, pp. 283–299, 1996.

Conference Papers

Åkesson, Mats: “Integrated control and diagnostics using robust control methods.” In *EURACO Workshop Robust and Adaptive Control of Integrated Systems*, Herrsching, Germany, October 1996.

Åkesson, Mats, Erik Gustafson, and Karl Henrik Johansson: “Control design for a helicopter lab process.” In *IFAC’96, Preprints 13th World Congress of IFAC*, San Francisco, California, July 1996.

Akke, Magnus, Jerker Linder, Bernt Nilsson, and Olof Samuelsson: “An object-oriented transformer model in Omola.” In *IFAC’96, Preprints 13th World Congress of IFAC*, vol. O, pp. 259–264, San Francisco, California, July 1996.

Andersson, Lennart, and Carolyn Beck: “Model comparison and simplification.” In *Proceedings of the 35th IEEE Conference on Decision and Control*, Kobe, Japan, 1996.

Årzén, Karl-Erik: “AI in the feedback loop: A survey of alternative approaches.” In *IFAC Workshop on AI in Real-Time Control*, Bled, Slovenia, 1995. Plenary address.

Årzén, Karl-Erik: "Experiences of using G2 for real-time process control." In *Workshop on Using G2 for Process Monitoring and Diagnosis*, Toulouse, France, 1995. Plenary address.

Årzén, Karl-Erik: "Grafchart: A graphical language for sequential supervisory control applications." In *IFAC'96, Preprints 13th World Congress of IFAC*, San Francisco, California, 1996.

Årzén, Karl-Erik: "A sequential function chart based approach to alarm filtering." In *IFAC'96, Preprints 13th World Congress of IFAC*, San Francisco, California, 1996.

Årzén, Karl-Erik, and Karl Johan Åström: "Expert control and fuzzy control: Differences and similarities." In Davis *et al.*, Eds., *International Conference on Intelligent Systems in Process Engineering, ISPE 95*, vol. 92 of *AIChE Symposium Series no. 312*, pp. 47–56. CACHE and AIChE, 1996.

Årzén, Karl-Erik, and Charlotta Johnsson: "Object-oriented SFC and ISA-S88.01 recipes." In *WBF'96—World Batch Forum*, Toronto, Canada, 1996.

Åström, Karl Johan: "Adaptive control around 1960." In *Proc. 34th IEEE Conference on Decision and Control*, pp. 2784–2789, New Orleans, Louisiana, 1995.

Åström, Karl Johan: "Tuning and adaptation." In *IFAC'96, Preprints 13th World Congress of IFAC*, pp. 1–18, San Francisco, California, 1996. Invited Plenary paper.

Åström, Karl Johan, and K. Furuta: "Swinging up a pendulum by energy control." In *IFAC'96, Preprints 13th World Congress of IFAC*, vol. E, pp. 37–42, San Francisco, California, July 1996.

Åström, Karl Johan, and Tore Hägglund: "New tuning methods for PID controllers." In *European Control Conference*, pp. 2456–2462, Rome, Italy, 1995.

Åström, Karl Johan, T. H. Lee, K. K. Tan, and K. H. Johansson: "Recent advances in relay feedback methods—a survey." In *IEEE SMC Conference*, pp. 2616–2621, Vancouver, Washington, 1995. Invited paper.

Åström, Karl Johan, and Björn Wittenmark: “A survey of adaptive control applications.” In *Proc. 34th IEEE Conference on Decision and Control*, pp. 649–654, New Orleans, Louisiana, 1995. Invited paper.

Bell, R. D., and Karl Johan Åström: “A fourth order non-linear model for drum-boiler dynamics.” In *IFAC’96, Preprints 13th World Congress of IFAC*, vol. O, pp. 31–36, San Francisco, California, July 1996.

Bernhardsson, Bo: “A summary on the real stability radius and real perturbation values.” In *EURACO Workshop Recent Results in Robust and Adaptive Control*, Florence, Italy, September 1995.

Bernhardsson, Bo, Anders Rantzer, and Li Qiu: “Real perturbation values and quadratic forms in complex vector space.” In *6th Conference of ILAS, International Linear Algebra Society*, Chemnitz, Germany, August 1996.

Eborn, Jonas, and Bernt Nilsson: “Simulation of a thermal power plant using an object-oriented model database.” In *IFAC’96, Preprints 13th World Congress of IFAC*, vol. O, pp. 121–126, San Francisco, California, July 1996.

Eborn, Jonas, and Henrik Olsson: “Modelling and simulation of an industrial control loop with friction.” In *Proceedings of the 4th IEEE Conference on Control Applications*, pp. 316–322, Albany, New York, September 1995.

Ferret, E., Mats Åkesson, and A. Chéruy: “Process control: Performance analysis of an original approach taking into account the positivity constraints on the process variables.” In *European Control Conference*, pp. 1161–1166, Rome, Italy, 1995.

Grundelius, Mattias, and David Angeli: “Adaptive control of systems with backlash acting on the input.” In *Proceedings of the 35th IEEE Conference on Decision and Control*, Kobe, Japan, December 1996.

Grundelius, Mattias, Sven Erik Mattsson, and Karl Johan Åström: “Object-oriented components for simulation of adaptive controllers.” In *Proceedings of the 35th IEEE Conference on Decision and Control*, pp. 2450–2455, Kobe, Japan, December 1996.

Gustafson, Erik, A. Åberg, and K. J. Åström: "Subsynchronous resonance, a controller for active damping." In *Proceedings of 4th IEEE Conference on Control Applications*, pp. 389–394, Albany, New York, September 1995.

Hagander, Per, and Anders Hansson: "How to solve singular discrete-time Riccati-equations." In *IFAC'96, Preprints 13th World Congress of IFAC*, vol. C, pp. 313–318, San Francisco, USA, July 1996.

Hägglund, Tore, and Anna Tengvall: "An automatic tuning procedure for unsymmetrical processes." In *European Control Conference*, Rome, Italy, 1995.

Haverkamp, B. R. J., C. T. Chou, M. Verhaegen, and Rolf Johansson: "Identification of continuous-time MIMO state space models from sampled data, in the presence of process and measurement noise." In *Proceedings of the 35th IEEE Conference on Decision and Control*, pp. 1539–1544, Kobe, Japan, December 1996.

Iwashiro, M., K. Furuta, and K. J. Åström: "Energy based control of pendulum." In *Proc. IEEE Conference on Control Applications*, pp. 715–720, Dearborn, Michigan, September 1996.

Johansson, Karl Henrik: "Performance limitations in coordinated control." In *EURACO workshop on robust and adaptive control of integrated systems*, Munich, Germany, October 1996.

Johansson, Karl Henrik, and Anders Rantzer: "Limit cycles in relay feedback systems." In *the Second Russian-Swedish Control Conference*, St Petersburg, Russia, 1995.

Johansson, Karl Henrik, and Anders Rantzer: "Global analysis of third-order relay feedback systems." In *IFAC'96, Preprints 13th World Congress of IFAC*, vol. E, pp. 55–60, San Francisco, California, July 1996.

Johansson, Mikael, and Karl Johan Åström: "Generalized spread-sheets for CACSD." In *Proc. of The IEEE International Symposium on CACSD*, Dearborn, Michigan, September 1996.

Johansson, Mikael, and Karl Johan Åström: "Virtual interactive systems for control education." In *Proceedings of the 35th IEEE Conference on Decision and Control*, pp. 3888–3889, Kobe, Japan, December 1996.

Johansson, Mikael, and Anders Rantzer: "A stability analysis for nonlinear and hybrid systems." In *Neural Adaptive Control Technology Workshop: NACT II*, Berlin, Germany, September 1996.

Johansson, Rolf: "Continued-fraction approximation for multivariable system identification." In *Proc. 34th IEEE Conference on Decision and Control*, pp. 691–696, New Orleans, Louisiana, 1995.

Johansson, Rolf, J. Ekblad, M. Magnusson, P.-A. Fransson, and M. Karlberg: "Analysis method for multi-stimulus multi-response posturography." In *XIXth Bárány Society Int. Meeting*, Sydney, Australia, August 1996.

Johansson, Rolf, and G. Lindstedt: "An algorithm for continuous-time state space identification." In *Proc. 34th IEEE Conference on Decision and Control*, pp. 721–726, New Orleans, Louisiana, 1995.

Johnsson, Charlotta, and Karl-Erik Årzén: "Batch recipe structuring using high-level Grafchart." In *IFAC'96, Preprints 13th World Congress of IFAC*, San Francisco, California, July 1996.

Johnsson, Charlotta, and Karl-Erik Årzén: "Object tokens in high-level Grafchart." In *CIMAT'96—Computer Integrated Manufacturing and Automation Technology*, Grenoble, France, 1996.

Jönsson, Ulf: "Robustness analysis based on integral quadratic constraints." In *EURACO Workshop Recent Results in Robust and Adaptive Control*, Florence, Italy, September 1995.

Jönsson, Ulf, and M. C. Laiou: "Stability analysis of systems with nonlinearities." In *Proceedings of the 35th IEEE Conference on Decision and Control*, Kobe, Japan, December 1996.

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

Jönsson, Ulf, and Anders Rantzer: "Duality bounds in robustness analysis." In *IFAC'96, Preprints 13th World Congress of IFAC*, vol. H, pp. 35–40, San Fransisco, California, June 1996.

Magnusson, M., Rolf Johansson, M. Karlberg, and P.-A. Fransson: "Availability of visual information changes the strategy of postural responses." In *XIXth Bárány Society Int. Meeting*, Sydney, Australia, August 1996.

Malmborg, Jörgen, Bo Bernhardsson, and Karl Johan Åström: "A stabilizing switching scheme for multi controller systems." In *IFAC'96, Preprints 13th World Congress of IFAC*, pp. 229–234, San Francisco, California, July 1996.

Mattsson, Sven Erik: "On object-oriented modelling of abrupt changes." In Breitenecker and Husinsky, Eds., *Eurosim '95 Simulation Congress*, pp. 433–438. Elsevier, September 1995.

Mattsson, Sven Erik: "On object-oriented modeling of relays and sliding mode behaviour." In *IFAC'96, Preprints 13th World Congress of IFAC*, vol. F, pp. 259–264, San Francisco, California, July 1996.

Mattsson, Sven Erik, Karl Johan Åström, and Rodney D. Bell: "A natural approach to modeling physical systems." In *Proceedings of the 35th IEEE Conference on Decision and Control*, pp. 199–200, Kobe, Japan, December 1996. Invited session paper.

Mylaraswamy, D., Anders Wallén, V. Venkatasubramanian, and Karl-Erik Årzén: "A model-based hybrid neural network architecture for fault diagnosis." In *AIChE Annual Meeting*, Miami Beach, Florida, 1996.

Nilsson, Bernt: "Experiences of Developing Process Model Libraries in Omola." In Davis *et al.*, Eds., *International Conference on Intelligent Systems in Process Engineering, ISPE'95*, vol. 92 of *AIChE Symposium Series no. 312*, pp. 388–392. CACHE and AIChE, 1996.

Nilsson, Bernt, and Jonas Eborn: "An object-oriented model database for thermal power plants." In Breitenecker and Husinsky, Eds., *Eurosim '95 Simulation Congress*, pp. 747–752. Elsevier, September 1995.

Nilsson, Johan, and Bo Bernhardsson: "Analysis of real-time control systems with time delays." *Proceedings of the 35th IEEE Conference on Decision and Control*, pp. 3173–3178, 1996.

Nilsson, Johan, Bo Bernhardsson, and Björn Wittenmark: "Stochastic analysis and control of real-time systems with random time delays." In *IFAC'96, Preprints 13th World Congress of IFAC*, San Francisco, California, 1996.

Nilsson, Klas, Rolf Johansson, Gunnar Bolmsjö, and Gustaf Olsson: "Experimental industrial robotics." In *Proceedings of the 35th IEEE Conference on Decision and Control*, pp. 3904–3909, Kobe, Japan, December 1996.

Olsson, Henrik: "On describing function analysis of systems with friction." In *Proceedings of the 4th IEEE Conference on Control Applications*, pp. 310–15, Albany, New York, 1995.

Olsson, Henrik, and Karl Johan Åström: "Friction generated limit cycles." In *Proc. IEEE International Conference on Control Applications*, pp. 798–803, Dearborn, Michigan, September 1996.

Olsson, Henrik, and Karl Johan Åström: "Observer-based friction compensation." In *Proceedings of the 35th IEEE Conference on Decision and Control*, pp. 4345–4350, Kobe, Japan, December 1996.

Pedersen, Lars Malcolm, and Björn Wittenmark: "Multivariable controller design for hot rolling mill." In *IFAC'96, Preprints 13th World Congress of IFAC*, vol. M, pp. 475–480, San Francisco, California, July 1996.

Petersen, H., M. Magnusson, Rolf Johansson, and P.-A. Fransson: "Auditory feedback regulation of perturbed stance in stroke patients." In *XIXth Bárány Society Int. Meeting*, Sydney, Australia, August 1996.

Petersen, H., M. Magnusson, Rolf Johansson, and P.-A. Fransson: "Interaction of vestibular input and body mechanics in the vestibulospinal reflex." In *XIXth Bárány Society Int. Meeting*, Sydney, Australia, August 1996.

Rantzer, Anders: “A note on the Kalman-Yakubovich-Popov lemma.” In *Proceedings of European Control Conference*, pp. 1792–1795, 1995.

Rantzer, Anders: “Control of nonlinear systems: Theory and applications.” In *Proceedings of the EURACO Tutorial Workshop*, pp. 15–21, Algarve, Portugal, 1996. Invited paper.

Rantzer, Anders: “Friction analysis based on Integral Quadratic Constraints.” In *Proceedings of the 35th IEEE Conference on Decision and Control*, pp. 3948–3952, Kobe, Japan, December 1996.

Rantzer, Anders, and A. Megretski: “Stability criteria based on Integral Quadratic Constraints.” In *Proceedings of the 35th IEEE Conference on Decision and Control*, pp. 215–220, Kobe, Japan, December 1996.

Savaresi, S., and Björn Wittenmark: “Robust narrow-band disturbance rejection using overparameterized pole-assignment control.” In *IMACS-IEEE Multiconference CESA'96*, Lille, France, July 1996.

Sobral, L., Rolf Johansson, G. Lindstedt, and G. Olsson: “Ultrasonic detection in robotic environments.” In *Proc. 1996 IEEE Conf. Robotics and Automation*, pp. 347–352, Minneapolis, Minnesota, 1996.

Suárez, D. A., R. Lozano, Karl Johan Åström, and Björn Wittenmark: “Adaptive control of linear systems with poles in the closed LHP with constrained inputs.” In *Proceedings of the 35th IEEE Conference on Decision and Control*, pp. 4351–4356, Kobe, Japan, December 1996.

van der Geest, Robert, and Anders Rantzer: “Quadratic performance of generalized first order systems.” In *Proceedings of the 35th IEEE Conference on Decision and Control*, pp. 4533–4534, Kobe, Japan, December 1996.

Viswanathan, S., V. Venkatasubramanian, Charlotta Johnsson, and Karl-Erik Årzén: “Knowledge representation and planning strategies for batch plant operating procedure synthesis.” In *AIChE Annual Meeting*, Chicago, Illinois, 1996.

Wallén, Anders: “Using Grafcet to structure control algorithms.” In *Proceedings of The Third European Control Conference*, Rome, Italy, 1995.

Conference Abstracts

Andersson, Lennart, and Carolyn Beck: “Simplification methods for uncertain models.” In *Reglermöte 96*, pp. 49–50, Luleå, Sweden, 1996.

Hägglund, Tore: “The Knocker—The controller that compensates for friction in valves.” In *Reglermöte 96*, Luleå, Sweden, 1996.

Jönsson, Ulf: “Stability analysis of systems with hysteresis nonlinearities.” In *Reglermöte 96*, Luleå, Sweden, June 1996.

Laiou, Maria Christina, and Ulf Jönsson: “Stability analysis of systems with nonlinearities.” In *Reglermöte 96*, Luleå, Sweden, June 1996.

Nilsson, Johan, Bo Bernhardsson, and Björn Wittenmark: “Stochastic analysis and control of real-time systems with random time delays.” In *Reglermöte 96*, Luleå, Sweden, 1996.

Wittenmark, Björn: “Tillämpningar av adaptiv reglering.” In *Reglermöte 96*, pp. 40–48, Luleå, Sweden, 1996. Invited paper, plenary talk.

Wittenmark, Björn, and Per-Olof Källén: “Robust adaptive control based on frequency domain analysis.” In *EURACO Workshop, Recent Results in Robust and Adaptive Control*, Florence, Italy, September 1995.

12. Reports

Three PhD theses and two Tech Lic theses have been published. The abstracts are presented in Chapter 8. Forty Master's theses have been completed and 18 internal reports.

Dissertations

Jönsson, Ulf: *Robustness Analysis of Uncertain and Nonlinear Systems*. PhD thesis ISRN LUTFD2/TFRT--1047--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1996.

Nilsson, Johan: *Analysis and Design of Real-Time Systems with Random Delays*. Lic Tech thesis ISRN LUTFD2/TFRT--3215--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 1996.

Nilsson, Klas: *Industrial Robot Programming*. PhD thesis ISRN LUTFD2/TFRT--1046--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 1996.

Olsson, Henrik: *Control Systems with Friction*. PhD thesis ISRN LUTFD2/TFRT--1045--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, April 1996.

Pedersen, Lars M.: "Multivariable thickness control of a hot rolling mill." Lic Tech thesis TFRT-3214, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1995.

Master's Theses

Abelson, Carl Fredrik: "The effect of friction on stabilization of an inverted pendulum." Master thesis ISRN LUTFD2/TFRT--5563--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1996.

Andersson, Jan: "Ett öppet system för programmering och styrning av robotar," (An open system for robot programming and control). Master thesis ISRN LUTFD2/TFRT--5557--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 1996.

Angeli, David: "Adaptive control of systems with backlash." Master thesis ISRN LUTFD2/TFRT--5553--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, February 1996.

Antius, Tobias: "Dynamic virtual realities with sound models." Master thesis ISRN LUTFD2/TFRT--5568--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 1996.

Aukland, Torbjörn: "Katalytisk avgasrening av fartygsmotorer," (Catalytic reduction in ship engines). Master thesis ISRN LUTFD2/TFRT--5565--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1996.

Calabresi, Michelangelo: "Control of unstable systems with input and rate saturations." Master thesis ISRN LUTFD2/TFRT--5562--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, August 1996.

Delin, Stefan: "Control of rolling missile based on measurement information from accelerometers." Master thesis ISRN LUTFD2/TFRT--5564--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1996.

Dufrène, Edith: "Improvements of a pid controller." Master thesis ISRN LUTFD2/TFRT--5559--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 1996.

Ekblad, Jonas: "Multivariable system identification of human postural control. a subspace method approach." Master thesis ISRN LUTFD2/TFRT--5556--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 1996.

Flygare, Helena: "Collision avoidance for an autonomous underwater vehicle." Master thesis ISRN LUTFD2/TFRT--5545--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 1995.

Gäfvert, Magnus: "Comparison of two friction models." Master thesis ISRN LUTFD2/TFRT--5561--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, June 1996.

Grundelius, Mattias: "Adaptiv reglering av system med glapp," (Adaptive control of systems with backlash). Master thesis ISRN LUTFD2/TFRT--5549--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, January 1996.

Haagensen, Richard: "Övervakning av regulatorer via internet," (Supervision of controllers using internet). Master thesis ISRN LUTFD2/TFRT--5569--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, October 1996.

Haglund, Helena: "Dynamic pictures in sampled data systems." Master thesis ISRN LUTFD2/TFRT--5542--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 1995.

Hellqvist, Johan: "Konzeption und realisierung eines echtzeitbetriebsystems für strukturadaptive regelsysteme," (Design and implementation of a real-time operating system for structure-adaptive control systems). Master thesis ISRN LUTFD2/TFRT--5558--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 1996.

Hendriks, Bart: "Implementation of industrial robot control." Master thesis ISRN LUTFD2/TFRT--5555--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 1996.

Holmgren, Ulf: "An adaptive driver model for computer simulations of dynamical vehicle systems." Master thesis ISRN LUTFD2/TFRT--5548--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, January 1996.

Johansson, Stefan, and Martin Öhman: "Prototype implementation of the PLC standard IEC 1131-3." Master thesis ISRN LUTFD2/TFRT--5547--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 1995.

Klevhag, Jonas: "Accuracy verification of continuous juice blending process using simulation." Master thesis ISRN LUTFD2/TFRT--5554--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 1996.

Laiou, Maria-Christina: "Analysis of static nonlinearities based on integral quadratic constraints." Master thesis ISRN LUTFD2/TFRT--5538--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1995.

McAleer, Richard: "An investigation of postural control with respect to a point of interest." Master thesis ISRN LUTFD2/TFRT--5552--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1995.

Meeuwse, Jan Peter: "Algorithms and tools for control of flexible servo systems." Master thesis ISRN LUTFD2/TFRT--5531--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, July 1995.

Nanevazadeh, Behroz: "The dynamic simulation of a humid air gas turbine unit." Master thesis ISRN LUTFD2/TFRT--5543--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 1995.

Nilsson, Hans: "Cross-coupling effects in submarine control." Master thesis ISRN LUTFD2/TFRT--5541--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 1995.

Nilsson, Patric: "Identification and simulation of paper machine." Master thesis ISRN LUTFD2/TFRT--5570--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 1996.

Nilsson, Stefan: “Simulering av släphydrofon,” (Simulation of towed array sonar). Master thesis ISRN LUTFD2/TFRT--5544--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 1995.

Nilsson, Staffan, and Andreas Fransson: “An experimental platform for DC-cable interaction with ship steering.” Master thesis ISRN LUTFD2/TFRT--5546--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 1995.

Overaa, Egil: “Robustness analysis of a wind power plant.” Master thesis ISRN LUTFD2/TFRT--5567--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1996.

Paiva, Rui Pedro P. C.: “Modelling and control of an electric arc furnace.” Master thesis ISRN LUTFD2/TFRT--5560--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, June 1996.

Panagopoulos, Hélène: “Singularly perturbed systems.” Master thesis ISRN LUTFD2/TFRT--5535--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, August 1995.

Persson, Per: “Kommunikation mot InterBus-S fältbuss under Windows NT,” (Communication between InterBus-S fieldbus and windows nt). Master thesis ISRN LUTFD2/TFRT--5533--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, August 1995.

Petersson, Henrik: “Modelling and object oriented implementation of a Windows based PLC configuration tool.” Master thesis ISRN LUTFD2/TFRT--5536--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1995.

Serrano, Cesar A. Mendoza: “Dynamic picture as a learning tool in control.” Master thesis ISRN LUTFD2/TFRT--5566--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1996.

Stendahl, Henrik: “Speed control of a switched reluctance motor.” Master thesis ISRN LUTFD2/TFRT--5551--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, February 1996.

Svensson, Stefan: “Desarrollo de herramientas de control adaptativo para el sistema SCM,” (Object oriented tools for adaptive control). Master thesis ISRN LUTFD2/TFRT--5534--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, July 1995.

Templin, Michael: “Integrated control and diagnosis using 4 DOF controllers.” Master thesis ISRN LUTFD2/TFRT--5550--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, February 1996.

Trageser, Bernd: “Performance improvement of pi-control using nonlinear feedforward.” Master thesis ISRN LUTFD2/TFRT--5571--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 1996.

Urquhart, Alexander: “Extremal seeking control.” Master thesis ISRN LUTFD2/TFRT--5537--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1995.

Wigren, Per: “Fuzzy adaptiv pH-reglering av vattenreningsverk,” (Fuzzy adaptive pH control of a water purification process). Master thesis ISRN LUTFD2/TFRT--5540--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, October 1995.

Yalirakis, Costas: “Singular perturbations and stability.” Master thesis ISRN LUTFD2/TFRT--5539--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1995.

Other Reports

Åkesson, Mats: “Integrated control and diagnostics using robust control methods.” Report ISRN LUTFD2/TFRT--7552--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, October 1996.

Åström, Karl Johan, Walter Schaufelberger, Sven Erik Mattsson, and Jonas Eborn: “COSY workshop, mathematical modeling of complex systems.” Report ISRN LUTFD2/TFRT--7551--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1996.

Bernhardsson, Bo: “Control system synthesis—the PhD course 1995.” Report ISRN LUTFD2/TFRT--7540--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 1995.

Dagnegård, Eva, and Karl Johan Åström: “Activity report 1994–1995.” Report ISRN LUTFD2/TFRT--4023--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 1995.

Eker, Johan, and Karl Johan Åström: “A C++ class for polynomial operation.” Report ISRN LUTFD2/TFRT--7541--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, December 1995.

Hägglund, Tore: “The knocker—a compensator for stiction in control valves.” Report ISRN LUTFD2/TFRT--7539--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 1995.

Hansson, Anders, and Per Hagander: “How to solve ill-posed semidefinite discrete-time algebraic riccati equations.” Report ISRN LUTFD2/TFRT--7554--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 1996.

Johansson, Karl Henrik, and Anders Rantzer: “Global analysis of third-order relay feedback systems.” Report ISRN LUTFD2/TFRT--7542--

SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, March 1996.

Johansson, Mikael: "A primer on fuzzy control." Report ISRN LUTFD2/TFRT--7545--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, January 1996.

Jönsson, Ulf: "Duality in analysis via integral quadratic constraints." Report ISRN LUTFD2/TFRT--7543--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, January 1996.

Jönsson, Ulf: "Stability analysis with popov multipliers and integral quadratic constraints." Report ISRN LUTFD2/TFRT--7546--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, April 1996.

Jönsson, Ulf: "Stability of uncertain systems with hysteresis nonlinearities." Report ISRN LUTFD2/TFRT--7548--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, May 1996.

Jönsson, Ulf, and Maria-Christina Laiou: "Multipliers for stability analysis of systems with nonlinearities." Report ISRN LUTFD2/TFRT--7547--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, April 1996.

Jönsson, Ulf, and Anders Rantzer: "Duality bounds in robustness analysis." Report ISRN LUTFD2/TFRT--7544--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, January 1996.

Nilsson, Bernt: "Simulation of process systems—a PhD course." Report ISRN LUTFD2/TFRT--7550--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, August 1996.

Rosenberg, Michael: "Nonlinear frequency control of an ultrasonic generator. Part II." Report ISRN LUTFD2/TFRT--7538--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1995.

Savaresi, Sergio, and Björn Wittenmark: "Robust narrow-band disturbances rejection using overparametrized pole-assignment control." Report ISRN LUTFD2/TFRT--7537--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, September 1995.

Simensen, Jo, Charlotta Johnsson, and Karl-Erik Årzén: "A framework for batch plant information models." Report ISRN LUTFD2/TFRT--7553--SE, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, November 1996.

Reports Available

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- Stockholms Universitetsbibliotek, Svenska Tryckavdelningen,
  S-106 91 Stockholm
- Kungliga Biblioteket, Box 5039, S-102 41 Stockholm
- Umeå Universitetsbibliotek, Box 718, S-901 10 Umeå
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13. Lectures by the Staff

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

Åkesson, Mats

Control Design for a Helicopter Lab Process, IFAC World Congress, San Francisco, California, July 1, 1996.

New Software for the Control Education in Lund, Education Day, Reglermöte 96, Luleå, June 5, 1996.

Integrated Control and Diagnosis Using Robust Control Methods, EURACO Workshop on Robust and Adaptive Control of Integrated Systems, Herrsching, Germany, October 18, 1996.

Andersson, Lennart

Simplification Methods for Uncertain Models, Reglermöte 96, Luleå, Sweden, June 7, 1996.

Simplification Methods for Uncertain Models, The Lund-Lyngby Day on Control, Lund Institute of Technology, May 10, 1996.

Model Comparison and Simplification, CDC'96, The 35th IEEE Conference on Decision and Control, Kobe, Japan, December 13, 1996.

Årzén, Karl-Erik

Expert Control and Fuzzy Control: Differences and Similarities, International Conference on Intelligent Systems in Process Engineering, Snowmass Colorado, July 11, 1995 (Invited Lecture).

Experiences of Using G2 for Real-Time Process Control, Workshop on using G2 for process monitoring and diagnosis, Toulouse, France, October 6, 1995 (Plenary Lecture).

AI in the Feedback Loop: A survey of alternative approaches, IFAC Workshop on AI in Real-Time Control, Bled, Slovenia, November 30, 1995 (Plenary Address).

Fuzzy Logic & Fuzzy Control, CelsiusTech, Stockholm, January 18, 1996.

Monitoring & Diagnosis and Industrial Control Systems, Ecole des Mines, Nantes, France, January 25, 1996.

Sequential Function Charts for Supervisory Control Applications, LAG, Grenoble, France, January 29, 1996.

Object-oriented SFC and ISA S88.01 recipes, World Batch Forum, Toronto, Canada, May 13, 1996.

A Sequential Function Chart Based Approach to Alarm Filtering, IFAC World Congress, San Francisco, California, July 3, 1996.

Grafchart: A Graphical Language for Sequential Supervisory Control Applications, IFAC World Congress, San Francisco, California, July 4, 1996.

Object-Oriented SFC: Application and Relations to IEC 1131-3, ISIS Workshop, Linköping University, November 28, 1996.

Åström, Karl Johan

Control of Complex Systems, COSY Workshop, European Science Foundation, Rome, Italy, September 6, 1995.

Automatic Control—A Perspective, COSY Workshop, European Science Foundation, Rome, Italy, September 6, 1995.

New Tuning Methods, European Control Conference, Rome, Italy, September 7, 1995.

Control of Hybrid Systems, Colloquium on Applications of Nonlinear and Adaptive Control to Physical Systems, European HCM Network on Nonlinear and Adaptive Control, Rome, Italy, September 9, 1995.

Nonlinear Adaptive Control, Colloquium on Applications of Nonlinear and Adaptive Control to Physical Systems, European HCM Network on Nonlinear and Adaptive Control, Rome, Italy, September 9, 1995.

Autonomous Process Control, The first S. M. Wu Lecture in Manufacturing Science, S. M. Wu Manufacturing Research Center, University of Michigan, Ann Arbor, Michigan, October 26, 1995.

Control of Hybrid Systems, Center for Intelligent Control. Laboratory for Information and Decision Systems, MIT, Cambridge, Massachusetts. October 31, 1995.

Autonomous Process Control, The Second Roger Sargent Lecture Imperial College of Science Technology and Medicine, London, November 21, 1995.

Relay Feedback, 1995 Eliahu I. and Joyce Jury Award Seminar. University of Miami, Florida, December 4, 1995.

A Survey of Adaptive Control Applications, Invited paper, CDC'95, 34th IEEE Conference on Decision and Control, New Orleans, Louisiana, December 13, 1995.

Adaptive Control Around 1960, CDC'95, 34th IEEE Conference on Decision and Control, New Orleans, Louisiana, December 14, 1995.

Control of Hybrid Systems, Daimler Benz Research, Berlin, Germany, January 15, 1996.

A Perspective on Automatic Control, Daimler Benz Technology Workshop on New Methods in Automatic Control Stuttgardt, Germany, January 16, 1996.

Interaction between Identification and Control Design in the Adaptive Control Framework, Workshop on Interaction between Identification and Control Design, Laboratoire d'Automatique, Grenoble, France, February 2, 1996.

Engineering Education, Royal Swedish Academy of Engineering Sciences (IVA), Stockholm, Sweden, March 6, 1996.

Adaptive Control, Eight Lectures in a graduate course at Department of Mechanical Engineering University of California, Berkeley, April 1–25, 1996.

Hybrid Systems, Department of Mechanical Engineering University of California, Berkeley, April 11, 1996

Control Systems with Relays, Department of Mechanical Engineering University of California, Berkeley, April 23, 1996.

Control of Hybrid Systems, Department of Electrical and Computer Engineering, University of California, Santa Barbara, April 26, 1996.

Automatic Control: a Perspective, University of Bologna, Italy, June 10, 1996.

Tuning and Adaptation, Plenary Lecture, IFAC World Congress, San Francisco, California, July 1, 1996.

Swinging up a Pendulum by Energy Control, IFAC World Congress, San Francisco, California, July 1, 1996.

Hybrid Systems, Singapore National University, Singapore, August 19, 1996.

Neural and Adaptive Control—Differences and Similarities, Neural Adaptive Control Technology Workshop NACT II, Daimler Benz, Berlin, Germany, September 9, 1996.

Recent Developments on Systems with Dynamic Friction, Workshop on Nonlinear and Adaptive Control, ENSIEG, Grenoble, France, September 17, 1996.

Industrial Control, Startup meeting, Centre for Autonomous Systems, Royal Institute of Technology, Stockholm, Sweden, October 1, 1996.

Adaptive Control—From Dreams to Reality, Scientific Colloquim on Robotics and System Dynamics, DLR, Wessling, Germany, October 7, 1996.

Nonlinear Observers, Valencia COSY Workshop, European Science Foundation, Universidad Politecnica de Valencia, Valencia, Spain, October 11, 1996.

Modeling of Complex Systems, Valencia COSY Workshop, European Science Foundation, Universidad Politecnica de Valencia, Valencia, Spain, October 12, 1996.

Autonomous Process Control, Centre for Autonomous Systems, Royal Institute of Technology, Stockholm, Sweden, November 13, 1996.

Limitations on Control System Performance, Center for Intelligent Control. Laboratory for Information and Decision Systems, MIT, Cambridge, Massachusetts, November 25, 1995.

Process Control, Royal Swedish Academy of Engineering Sciences (IVA), Stockholm, Sweden, November 28, 1996.

Bernhardsson, Bo

A Summary on the Real Stability Radius, and Real Perturbation Values. Euraco, Florence, Italy, September 13, 1995.

Computation of the Real Stability Radius, Dept of Mathematics, Lund Institute of Technology, Lund, Sweden, May 8, 1996.

Stochastic Analysis and Control of Real Time Systems with random Time Delays, The Lund-Lyngby Day on Control, Lund Institute of Technology, May 10, 1996.

Some Control Theory Research Problems, Dept of Mathematics, Lund Institute of Technology, December 6, 1996.

Eborn, Jonas

Modelling and Simulation of an Industrial Control Loop, 4th IEEE Conference on Control Applications, Albany, September 28, 1995.

An Object-Oriented Model Database for Thermal Power Plants, Electricité de France/DER Chatou, Paris, France, June 7, 1996.

Modelling and Simulation of a Thermal Power Plant, Electricité de France/DER Chatou, Paris, France, June 7, 1996.

Simulation of a Thermal Power Plant Using an Obejct-Oriented Model Database, Poster presentation, 13th IFAC World Congress, San Francisco, California, July 3, 1996.

Eker, Johan

A Nonlinear Observer for the Inverted Pendulum, Carnegie Mellon University, Pittsburgh, Pennsylvania, April 1996.

Structured Interactive Approach to Embedded Control, Software Engineering Institute/Carnegie Mellon University, Pittsburgh, Pennsylvania, April 1996.

Grundelius, Mattias

Adaptive Control of Systems with Backlash, Valencia COSY Workshop, Valencia, Spain, October 11, 1996.

Adaptive Control of Systems with Backlash, The Lund-Lyngby Day on Control, Technical University of Denmark, October 25, 1996.

Adaptive Control of Systems with Backlash Acting of the Input, CDC'96, The 35th IEEE Conference on Decision and Control, Kobe, Japan, December 12, 1996.

Object-Oriented Components for Simulation of Adaptive Controllers, CDC'96, The 35th IEEE Conference on Decision and Control, Kobe, Japan, Japan. December 13, 1996.

Hagander, Per

How to Solve Singular Discrete-Time Riccati-Equations, Invited lecture. LAG, Grenoble, France, July 11, 1995.

Hägglund, Tore

An Automatic Tuning Procedure for Unsymmetrical Processes, European Control Conference, Rome, Italy, September 7, 1995.

Modern Control Techniques Used in Process Industry, Stora, Gruvön, Sweden, January 10 and 11, 1996.

The Knocker—The Controller that Compensates for Friction in Valves, Reglermöte 96, Luleå, Sweden, June 7, 1996.

A Control Loop Performance Monitor, The Lund-Lyngby Day on Control, Technical University of Denmark, Lyngby, Denmark, October 25, 1996.

Control Methods Applied in Process Control, Workshop arranged by Alfa Laval AS, Oslo, Norway, September 11, 1996.

Johansson, Karl Henrik

Limit Cycles in Relay Feedback Systems, The Second Russian-Swedish Control Conference, St Petersburg, Russia, August 29, 1995.

Limit Cycles in Relay Feedback Systems, Systems and Control Group, University of Twente, The Netherlands, September 14, 1995.

Global Analysis of Third-Order Relay Feedback Systems, IFAC World Congress, San Francisco, California, July 1, 1996.

Performance Limitations in Coordinated Control, EURACO workshop on robust and adaptive control of integrated systems, Munich, Germany, October 16, 1996.

Johansson, Mikael

Computation of Piecewise Quadratic Lyapunov Functions for Hybrid Systems, The Lund-Lyngby Day on Control, Technical University of Denmark, Lyngby, Denmark, October 25, 1996.

Generalized Spread-Sheets for CACSD, IEEE International Symposium on CACSD, Dearborn, Michigan, September 1996.

A Stability Analysis of Nonlinear and Hybrid Systems, Neural Adaptive Control Technology Workshop NACT II, Daimler Benz, Berlin, Germany, September 1996.

Virtual Interactive Systems for Control Education, CDC'96, The 35th IEEE Conference on Decision and Control, Kobe, Japan, December 1996.

Johansson, Rolf

Multivariable System Identification via Continued-Fraction Approximation, Caltech Control and Dynamical Systems CDS) Seminar. California Institute of Technology, Pasadena, California, December 7, 1995.

An Algorithm for Continuous-Time State Space Identification, 34th IEEE Conf. Decision and Control, New Orleans, Louisiana, December 13, 1995.

Continued-Fraction Approximation for Multivariable System Identification, 34th IEEE Conf. Decision and Control, New Orleans, Louisiana, December 13, 1995.

System Identification as Statistical Methodology in Medical Science, Invited lecture. Dept Clinical Neurophysiology, Lund University, Lund, Sweden, February 16, 1996.

System Modeling and Identification, Invited lecture. Dept. Psychology, Lund University, Lund, Sweden, April 18, 1996.

An Algorithm for Continuous-Time State Space Identification, Yale University, New Haven, Connecticut, April 22, 1996.

Ultrasonic Detection in Robotic Environments, 1996 IEEE Conf. Robotics and Automation, Minneapolis, Minnesota, April 24, 1996.

Experimental Industrial Robotics, Dept Mechanical Engineering, Gifu University, Gifu, Japan, December 10, 1996.

Experimental Industrial Robotics, CDC'96, The 35th IEEE Conference on Decision and Control, Kobe, Japan, December 13, 1996.

Johnsson, Charlotta

Batch Recipe Structuring Using High-Level Grafchart, The Lund-Lyngby Day on Control, Lund Institute of Technology, Lund, Sweden, May 10, 1996.

Object Tokens in High-Level Grafchart, CIMAT'96—Computer Integrated Manufacturing and Automation Technology, Grenoble, France, May 29, 1996.

Batch Recipe Structuring Using High-Level Grafchart, IFAC World Congress, San Francisco, California, July 5, 1996.

Jönsson, Ulf

Robustness Analysis Based on Integral Quadratic Constraints, Euraco Workshop, Recent Results in Robust and Adaptive Control, Florence, Italy, September 11–14, 1995.

On Duality in Robustness Analysis, 34th IEEE Conference on Decision and Control, New Orleans, Lousiana, December 1995.

Robustness Analysis of Uncertain and Nonlinear Systems, Invited lecture. Linköping University, November 14, 1996.

Robustness Analysis of Uncertain and Nonlinear Systems, Invited lecture. The Technical University of Denmark (DTU), Denmark, November 19, 1996.

Malmborg, Jörgen

Stability of Multi Controller Systems, Invited lecture. European project on Human Capital Mobility. Roma, Italy, September 9, 1995.

An Approach to Hybrid Systems, Block Island Workshop On Control Using Logic-Based Switching. Block Island, Rhode Island, October 1, 1995.

A Stabilizing Switching Scheme for Multi Controller Systems, IFAC World Congress. San Francisco, California, July 1, 1996.

Simulation and Analysis of Hybrid Control System, WCNA World Congress. Athens, Greece, July 12, 1996.

Mattsson, Sven Erik

On Object-Oriented Modelling of Abrupt Changes, EUROSIM Congress '95, Vienna, Austria, September 13, 1995.

Modelling and Simulation of Complex Systems, Poster at the annual Program Conference of NUTEK's research programme "Complex Systems," Stockholm, Sweden, November 1, 1995.

Activities in the Project 'Modelling and Control of Energy Processes', Sydkraft Konsult AB, Malmö, Sweden, May 3, 1996.

Presentation of the Department, Electricité de France/DER Chatou, Paris, France, June 7, 1996.

Object-Oriented Modelling of Hybrid Technical Systems, Electricité de France/DER Chatou, Paris, France, June 7, 1996.

Power Quality Simulation—What Are the Problems?, Workshop and technical seminar on power quality arranged by Elforsk in cooperation with EPRI, Stockholm, Sweden, June 19, 1996.

On Object-Oriented Modeling of Relays and Sliding Mode Behaviour, Poster presentation, IFAC World Congress, San Francisco, California, July 1, 1996.

Modeling and Simulation of Hybrid Complex Systems, COSY Workshop on Mathematical Modeling of Complex Systems, Lund, Sweden, September 5, 1996.

A Natural Approach to Modeling Physical Systems, Invited session paper. CDC'96, The 35th IEEE Conference on Decision and Control, Kobe, Japan, December 11, 1996.

Möllerstedt, Erik

Subsynchronous Resonance—A Controller for Active Damping, IEEE Conference on Control Applications, Albany, New York, September 28, 1995.

Nilsson, Bernt

Experiences of Describing Process Model Libraries in Omola, ISPE'95, Snowmass Village, Colorado, July 11, 1995.

An Object-Oriented Model Database for Thermal Power Plants, EUROSIM'95, Vienna, Austria, September 12, 1995.

Simulation of Process Systems, A PhD course at department of Chemical Engineering II (7 lectures and 5 exercises), Lund, Sweden, April 16, 1996.

Object-Oriented Modelling in Lund, Two lectures in the PhD course Object-Oriented Modelling and Computer Algebra at Department of Computer Science at Linköping Institute of Technology, Linköping, Sweden, June 11, 1996.

Nilsson, Johan

Stochastic Analysis and Control of Real-time Systems with Random Time Delays, Reglermöte 96, Luleå, Sweden, June 7, 1996.

Stochastic Analysis and Control of Real-time Systems with Random Time Delays, IFAC World Congress, San Francisco, California, July 3, 1996.

Analysis of Real-Time Control Systems with Time Delays, CDC'96, The 35th IEEE Conference on Decision and Control, Kobe, Japan, December 13, 1996.

Olsson, Henrik

Limit Cycles in Control Systems with Friction, HCM Colloquim on Applications of Nonlinear and Adaptive Control to Physical Systems, Rome, Italy, September 9, 1995.

Describing Function Analysis of a System with Friction, IEEE Conference on Control Applications, Albany, New York, September 28, 1995.

Rantzer, Anders

Relays and Delays in Linear Systems, Invited lecture. Bernoulli workshop on Control of Uncertain Systems, Groningen, The Netherlands, August 28, 1995.

A Note on the Kalman-Yakubovich-Popov Lemma, European Control Conference, Rome, Italy, September 7, 1995.

Error Bounds for Truncation of Uncertain Systems, KTH, Stockholm, Sweden, October 20, 1995.

Error Bounds for Truncation of Uncertain Systems, Invited lecture, ERCIM Workshop on Systems and Control, Budapest, Hungary, November 7, 1995.

Friction Analysis Based on Integral Quadratic Constraints, LiTH, Linköping, Sweden, March 18, 1996.

Stability Analysis of Nonlinear Systems, EURACO Tutorial Workshop, Algarve, Portugal, May 13, 1996.

Linearisation and Scheduling for Nonlinear Control, EURACO Tutorial Workshop, Algarve, Portugal, May 13, 1996.

Error Bounds for Model Reduction with Restricted Input Signals, MTNS 96, St. Louis, June 25, 1996.

Friction Analysis Based on Integral Quadratic Constraints, Invited lecture. Workshop on Nonlinear and Adaptive Control Designs and Applications, Univ of California, Santa Barbara, California, June 28, 1996.

Model Reduction via Integral Quadratic Constraints, International Workshop on Robust Control, Napa, California, June 30, 1996.

System Analysis via Integral Quadratic Constraints, Valencia COSY Workshop, Valencia, Spain, October 11, 1996.

Frequency Analysis of Nonlinear Systems, CTH, Gothenburg, Sweden, December 4, 1996.

Stability Analysis via Integral Quadratic Constraints, CDC'96, The 35th IEEE Conference on Decision and Control, Kobe, Japan, December 11, 1996.

Friction Analysis Based on Integral Quadratic Constraints, CDC'96, The 35th IEEE Conference on Decision and Control, Kobe, Japan, December 13, 1996.

Observer-based Friction Compensation, CDC'96, The 35th IEEE Conference on Decision and Control, Kobe, Japan, December 13, 1996.

Nonlinear System Analysis via Linear Matrix Inequalities, Invited lecture at Tokyo Institute of Technology, Japan, December 14, 1996.

System Analysis via Integral Quadratic Constraints, Invited lecture at HKUST Minisymposium on Robust Control and Identification, Hong Kong, December 16, 1996.

Wallén, Anders

Using Grafcet to Structure Control Algorithms, European Control Conference, Rome, Italy, September 8, 1995.

Valve Diagnostics and Automatic Tuning, EURACO Workshop on Robust and Adaptive Control of Integrated Systems, Herrsching, Germany, October 18, 1996.

Wittenmark, Björn

Robust Adaptive Control Based on Frequency Domain Analysis, EURACO Workshop on Recent Results in Robust and Adaptive Control, Florence, Italy, September 13, 1995.

Adaptive Control, Invited PhD course. Louvain-la-Neuve, Belgium, October 15–25, 1995.

Adaptive Extremal Control, Louvain-la-Neuve, Belgium, October 24, 1995.

Adaptive Extremal Control, Aalborg University, Denmark, November 14, 1995.

Dynamic Pictures in Automatic Control Education, Invited lecture. Lund Institute of Technology, Lund, Sweden, April 18, 1996.

Use of Internet for Courses in Lund and an Education Module in Digital Control, Education Day, Reglermöte 96, Luleå, Sweden, June 5, 1996.

Applications of Adaptive Control, Invited plenary lecture, Reglermötet 96, Luleå, Sweden, June 6, 1996.

14. Seminars at the Department

Seminars presented in order of date. The seminars were given at the department during the period July 1995 – December 1996, both by the staff and by invited lecturers. Disserterations and master theses presentations are also included.

AC = Department of Automatic Control, Lund Institute of Technology
LTH = Lund Institute of Technology

Alexander Megretski (Iowa State University): *Stabilization of Linear Systems with Saturation Limits on Control.* Aug 7, 1995.

Li Qiu (Hong Kong Univ. of Science and Technology): *Optimal Control of Multirate Sampled-Data Systems.* Aug 9, 1995.

Per Persson (LTH): *Communication between InterBus-S fieldbus and Windows NT.* Aug 9, 1995. MSc-thesis presentation.

Richard Murray (Caltech): *Nonlinear Control of Mechanical Systems: A Lagrangian Perspective.* Aug 16, 1995.

Richard Murray (Caltech): *Exterior Differential Systems and Nonlinear Control.* Aug 18, 1995.

Helene Panagopoulos (LTH): *Singularly Perturbed Systems.* Aug 18, 1995. MSc-thesis presentation.

Richard Murray (Caltech): *Active Control of Rotating Stall Using Pulsed Air Injection.* Aug 21, 1995.

Ilya Ioslovich (Technion, Haifa, Israel): *Problems of Optimal Control of Cyclic Processes.* Aug 23, 1995.

Henrik Petersson (LTH): *Modelling and Object-Oriented Implementation of a Window-based PLC Configuration Tool.* Sep 5, 1995. MSc-thesis presentation.

Jonas Eborn (AC): *Integrated Modeling of Physical System Dynamics — Experiences from a course at Univ. Twente, Holland.* Sep 13, 1995.

Sergio Savaresi (Politecnico di Milano): *Robust Narrow-Band Disturbances Rejection using Overparametrized Pole-Assignment Control.* Sep 15, 1995.

Anders Hansson (Landis & Gyr, Switzerland): *Control of CO_2 in HVAC Installations.* Sep 19, 1995.

Alexander K. Urquhart (Imperial College): *Extremal Seeking Control.* Sep 19, 1995.

Maria Christina Laiou (Imperial College): *Analysis of Static Nonlinearities by Integral Quadratic Constraints.* Sep 20, 1995. MSc-thesis presentation.

Lars Malcolm Pedersen (The Danish Steelworks, Ltd, Denmark): *Multivariable Thickness Control of a Hot Rolling Mill.* Sep 22, 1995. Lic Tech dissertation seminar.

Torkel Glad (Linköping Institute of Technology): *Stabilisering med amplitud- och derivatabegränsning.* Sep 22, 1995.

Alf Isaksson (KTH): *Grey-Box Identification of a TMP Refiner.* Sep 25, 1995.

Bruce J. Allison (University of British Columbia): *Generalized Predictive Control Of Chip Level In Dual-Vessel Continuous Digesters.* Sep 26, 1995.

Costas Yalirakis (Imperial College, London): *Singular Perturbations and Stability.* Sep 26, 1995. MSc-thesis presentation.

Anders Robertsson (LTH): *Feedback and Non-Minimum Phase Systems.* Oct 4, 1995.

Lei Guo (Chinese Academy of Sciences, Beijing): *Self-Convergence of Weighted Least-Squares with Applications to Stochastic Adaptive Control.* Oct 5, 1995.

Michel Gevers (Catholic University of Louvain, Belgium): *Identification for Control.* Oct 10, 1995.

Per Wigren (LTH): *Fuzzy Adaptive pH Control of a Water Purification Process.* Oct 10, 1995. MSc-thesis presentation.

Michel Gevers (Catholic University of Louvain, Belgium): *Iterative Controller Design Schemes.* Oct 11, 1995.

Roger Germundsson (LiTH): *Symbolic Systems—Theory, Computation and Applications.* Oct 17, 1995.

Bill Bialkovsky (EnTech Control Engineering, Canada): *The Challenges of Manufacturing Uniform Paper Efficiently: A Perspective Based on Mill Variability Data, Control Engineering and Education.* Oct 20, 1995.

Tomas McKelvey (LiTH): *System Identification from Frequency Data using Subspace Methods.* Oct 24, 1995.

Hans Nilsson (LTH): *Cross-coupling Effects in Submarine Control.* Oct 31, 1995. MSc-thesis presentation.

Behroz Nanevazadeh (LTH): *Dynamic Simulation of a Humid Air Gas Turbine Unit.* Oct 31, 1995. MSc-thesis presentation.

Karl Johan Åström (AC): *Fundamental Limitations of Control System Performance.* Nov 14, 1995.

Peter Gärdenfors (LTH): *Presentation of the Cognitive Laboratory.* Nov 15, 1995.

Stefan Nilsson (LTH): *Simulation of Towed Array Sonar.* Nov 21, 1995. MSc-thesis presentation.

Erno Keskinen (Tampere University of Technology) *Simulation of Hydraulic Driven Machine Systems.* With examples, animation and video sequences. Nov 23, 1995.

Helena Haglund *Dynamic Pictures in Sampled Data Systems.* Nov 28, 1995. MSc-thesis presentation.

Ulf Jönsson (LTH): *Duality Bounds in Robustness Analysis.* Dec 5, 1995.

Helena Flygare (LTH): *Collision Avoidance for an Autonomous Underwater Vehicle (AUV).* Dec 11, 1995. MSc-thesis presentation.

Staffan Nilsson, Andreas Fransson (LTH): *An Experimental Platform for DC-cable Interaction with Ship Steering.* Dec 18, 1995. MSc-thesis presentation.

Ulf Holmgren (LTH): *An Adaptive Driver Model for Computer Simulations of Dynamical Vehicle Systems.* MSc-thesis presentation. Dec 19, 1995.

Stefan Johansson, Martin Öhman (LTH): *Prototype Implementation of the PLC standard IEC 1131-3.* Dec 19, 1995. MSc-thesis presentation.

Karl Johan Åström (AC): *Thoughts about the Future of Automatic Control.* Dec 20, 1995.

Martin Fabian (Chalmers, Gothenburg): *On Object-Oriented Nondeterministic Supervisory Control.* Jan 17, 1996.

Michael Tittus (Chalmers, Gothenburg): *Control Synthesis for Batch Processes.* Jan 17, 1996.

Robert van der Geest (University of Twente): *Stabilization of Behaviours.* Jan 23, 1996.

A. J. van der Schaft (University of Twente): *Hybrid Systems Described by Complementary-slackness Conditions.* Jan 25, 1996.

Michael Templin (LTH): *Integrated Control and Diagnosis using 4 DOF Controllers.* Feb 6, 1996. MSc-thesis presentation.

Anders Helmersson (Linköping): *Real μ Synthesis and Gain Scheduling.* Feb 7, 1996.

Tomas Bergström, Knut Mårtensson (Alfa Laval Automation): *Demonstration of the new SattLine Soft PLC with AD/DA for PC.* Feb 9, 1996.

Henrik Stendahl (LTH): *Speed Control of a Switched Reluctance Motor.* Feb 13, 1996.

David Angeli (University of Florence, Italy): *Adaptive Control of Systems with Backlash.* Feb 13, 1996.

Carolyn Beck (California Institute of Technology): *Model Reduction for Control of Uncertain Systems.* Feb 14, 1996.

Anders Rantzer (AC): *Error Bounds for Truncation of Uncertain Systems.* Feb 21, 1996.

Lennart Andersson (AC): *My visit to Caltech—Simplification Methods for Uncertain Models.* Feb 21, 1996.

Krister Forsman (ABB Corporate Research): *Paper Machine Control in Practice.* Feb 28, 1996.

Jonas Klevhag (LTH): *Accuracy Verification of a Continuous Juice Blending Process using Simulation.* Mar 12, 1996. MSc-thesis presentation.

Johan Hellqvist (LTH): *Design and Implementation of a Real-Time System for Structure-Adaptive Control.* Mar 19, 1996. MSc-thesis presentation.

Jonas Ekblad (LTH): *Multivariable System Identification of Human Postural Control.* Mar 19, 1996. MSc-thesis presentation.

Carsten Scherer (Delft University of Technology): *Linear Matrix Inequalities in Robust Control.* Mar 26, 1996.

Bart Hendriks (Delft University of Technology): *Experimental Control of Industrial Robots.* Mar 27, 1996. MSc-thesis presentation.

Carsten Scherer (Delft University of Technology): *The H_∞ Problem at Optimality and the Nonstrict Algebraic Riccati Inequality.* Mar 28, 1996.

Jan Andersson (LTH): *An Open System for Robot Programming and Control.* May 2, 1996. MSc-thesis presentation.

Vladimir A. Yakubovich (St Petersburg University) *Nonconvex Optimal Control Problems.* May 7, 1996.

Johan Nilsson (AC): *Analysis and Design of Real-Time Systems with Random Delays.* May 8, 1996. Lic Tech dissertation seminar.

Rolf Johansson (AC): *Video from IEEE Robotics and Automation Conference.* May 14, 1996.

Karl Johan Åström (AC): *Experiences from Berkeley.* May 14, 1996.

Bernard Friedland (New Jersey Institute of Technology): *The Golden Age of Control Systems Research at Columbia University.* May 21, 1996.

Bernard Friedland (New Jersey Institute of Technology): *Friction Modeling and Compensation.* May 22, 1996.

Mogens Blanke (Ålborg University): *Fault Tolerant Control System Design using Automated Methods from Risk Analysis.* May 23, 1996.

Henrik Olsson (AC): *Control Systems with Friction.* May 24, 1996. Doctoral dissertation defence.

Nadia Pariset (Ecole des Mines de Nantes, France): *Implementation of Hybrid Petri Nets in Omola.* May 28, 1996. MSc-thesis presentation.

Geir Dullerud (University of Waterloo, Canada): *Control of Uncertain Sampled-data Systems.* May 28, 1996.

Carlos Canudas de Wit (Lab d'Automatique de Grenoble): *Adaptive Friction Compensation in Systems with Dynamic Friction.* May 28, 1996.

Bernard Friedland (New Jersey Institute of Technology): *Control of Processes with Parasitic Nonlinearities.* May 28, 1996.

Klas Nilsson (AC): *Industrial Robot Programming.* May 29, 1996. Doctoral dissertation defence.

Bernard Friedland (New Jersey Institute of Technology): *Norbert Wiener's Impact on Control Systems Research.* May 29, 1996.

Mark W. Spong (Univ of Illinois at Urbana-Champaign): *Invariant Manifolds, Control of Energy and Robot Gymnastics.* May 30, 1996.

Bo Sanden (George Mason University): Intensive 3-days course. *Design of Concurrent Software.* June 3–5, 1996.

Ken Hunt (Daimler-Benz Research, Berlin): *Wide-envelope Control of Nonlinear Systems via Local Dynamics Shaping.* June 5, 1996.

Pascale Bendotti (Electricite de France, Paris): *Modelling and Control of a Pressurized Water Reactor using Multidimensional Model Reduction and mu-Synthesis Techniques.* June 12, 1996.

Rui Pedro Paiva (Universidade de Coimbra, Portugal): *Modelling and Control of an Electric Arc Furnace.* June 12, 1996. MSc-thesis presentation.

Sanjoy Mitter (MIT): *The Linear Quadratic Gaussian Problem with Communication Constraints.* June 13, 1996.

Ola Dahl (Kockums Submarine Systems): *Submarine Control—Autopilot Design and Weight Compensation.*

Per-Olof Gutman (KTH): *Some Algorithmic Problems in Connection with QFT.* Aug 13, 1996.

Michelangelo Calabresi (University of Rome, Italy): *Control of Unstable Systems with Input and Rate Limitations.* Aug 16, 1996. MSc-thesis presentation.

Michel Verhaegen (TU, Delft): *Subspace Model Identification—SMI: A Way to Simplify the Toolset for Identification of MIMO LTI Systems.* Aug 21, 1996.

Michel Verhaegen (TU, Delft): *Subspace Model Identification—A Class of Algorithms for SMI.* Aug 22, 1996.

Michel Verhaegen (TU, Delft): *Subspace Model Identification—Identifying an Industrial Distillation Column via SMI.* Aug 23, 1996.

Chou Tung (TU, Delft): *Continuous Time Identification of SISO Systems Using Laguerre Functions.* Aug 23, 1996.

Nina Thornhill (University College, London): *Refinery Control Loop Performance Assessment.* Sep 2, 1996.

Stefan Delin (LTH): *Accelerometers in a Rolling Missile.* Sep 4, 1996. MSc-thesis presentation.

Carl Fredrik Abelson (LTH): *The effect of friction on stabilization of an inverted pendulum.* Sep 4, 1996. MSc-thesis presentation.

Hassan Khalil (Michigan State University): *Nonlinear Output Feedback Control.* Sep 12, 1996.

Torbjörn Aukland *Catalyctic Reduction in Ship Engines.* Sep 18, 1996. MSc-thesis presentation.

Joseph Wright (Pulp and Paper Research Insititute of Canada): *Process Control Activities at Paprican.* Sep 20, 1996.

John Seem (Johnson Controls Inc., Wisconsin): *A New Pattern Recognition Adaptive Controller.* Sep 23, 1996.

Cesar Mendoza Serrano (Imperial College, London): *Dynamic Pictures as a Learning Tool in Control.* Sep 27, 1996. MSc-thesis presentation.

Egil Overaa (Imperial College, London): *Robust Analysis of a Wind Power Plant.* Sep 27, 1996. MSc-thesis presentation.

Martin Otter (German Aerospace Research Establishment Oberpfaffenhofen (DLR), Germany): *Basic Techniques in Object-Oriented Modeling.* Oct 8, 1996.

Martin Otter (DLR, Germany): *Advanced Techniques in Object-Oriented Modeling.* Oct 15, 1996.

Guy Dumont (Pulp and Paper Centre, Univ. of British Columbia): *Control Loop Performance Monitoring and other projects at UBC-PPC.* Oct 15, 1996.

Stefan Pettersson (Chalmers): Hybrid seminar series: *Stability Analysis and Controller Design for Hybrid Systems.* Oct 16, 1996.

Martin Otter (DLR, Germany): *Basic Equations of Mechanical Systems.* Oct 22, 1996.

Alexander Stotsky (Institute for Problems of Mechanical Engineering, St Petersburg): *On Roadway Control for Automated Highway System.* Oct 23, 1996.

Martin Otter (DLR, Germany): *Object-Oriented Modeling of Multibody Systems.* Oct 29, 1996.

Munther Dahleh (Massachusetts Institute of Technology): *Control-Oriented System Identification.* Oct 31, 1996.

Bassam Bamieh (University of Illinois at Urbana-Champaign): *Robust Digital Control; Inter-sample and finite wordlength effects.* Oct 31, 1996.

Ulf Jönsson (AC): *Robustness Analysis of Uncertain and Nonlinear Systems.* Nov 1, 1996. Doctoral dissertation defence.

Hector Sussman (Rutgers University, New Jersey): *The Maximum Principle, Nonsmooth Versions, Version for Differential Inclusions, and Recent Developments.* Nov 4, 1996.

Hector Sussman (Rutgers University, New Jersey): *The Maximum Principle in Conjunction with Differential-Geometric Ideas. Structure of Optimal Trajectories.* Nov 6, 1996.

Hector Sussman (Rutgers University, New Jersey): *Reachable Sets and Optimal Regulator Synthesis.* Nov 8, 1996.

Lui Sha (Carnegie Mellon University): *Real-Time Control course: Rate-Monotonic Scheduling.* Nov 5, 1996.

Lui Sha (Carnegie Mellon University): *Fault-Tolerant Computer Control.* Nov 7, 1996.

Ulf Jönsson (AC): *A Tour through My Thesis.* Nov 11, 1996.

Hector Sussman (Rutgers University, New Jersey): *Generalized differentials, open mapping theorems, and a general version of the maximum principle under very weak hypotheses.* Nov 12, 1996.

Pericles R. Barros (Universidade Federal da Paraiba, Brazil) *On a Pole-Placement Iterative Design Scheme.* Nov 14, 1996.

Tobias Antius (LTH): *Dynamic Virtual Realities with Sound Models.* Nov 19, 1996. MSc-thesis presentation.

Magnus Gäfvert (LTH): *Comparison of Two Friction Models.* Nov 21, 1996. MSc-thesis presentation.

Krister Edström (Linköping): Hybrid seminar series: *Switched Bond Graphs.* Nov 21, 1996.

Daniel Rivera (Arizona State University): *System Identification for Process Control: Challenges, Opportunities, and New Directions.* Nov 25, 1996.

Patric Nilsson (LTH): *Identifiering och simulering av pappersmaskin.* Nov 28, 1996. MSc-thesis presentation.

Maria Seron, Julio Braslavsky (University of Newcastle, Australia): Minicourse on *Fundamental Limitations in Filtering and Control.* Dec 2–3, 1996.

Victor Terpstra (TU, Delft): *The Theory and Techniques Behind Production Scheduling in the Process Industry.* Dec 4, 1996.

Victor Terpstra (TU, Delft): *A "True"-Interactive, Constraint-Based Batch Scheduling System—I (an overview).* Dec 5, 1996.

Victor Terpstra (TU, Delft): *Overview of and Discussion on Techniques to Model and Solve Scheduling Problems.* Dec 10, 1996.

Victor Terpstra (TU, Delft): *A "True"-Interactive, Constraint-Based Batch Scheduling System—II (techniques).* Dec 12, 1996.

Bernd Trageser (Technische Hochschule, Darmstadt): *Improvement of Conventional PI-Control Using Nonlinear Feedforward Control.* Dec 16, 1996. MSc-thesis presentation.

Anders Henriksson (LTH): *Java-Based Picture Editing and Monitoring for Power Control Systems.* Dec 18, 1996. MSc-thesis presentation.