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ABSTRACT

The report gives a survey of the activity at the Department of Automatic Control during the academic year 1973-1974. Five different courses in automatic control are given at the civ.ing. degree (≈MS). About 260 students participated in one or more courses. 21 MS theses have been completed. In the graduate program four PhD theses have been completed. The main research effort is centered around process control. The projects include system identification, adaptive control, computational control, computer aided design of control systems, real-time computing, system theory, non-technical systems and applications. In the year 37 published papers and 44 technical reports have been written.

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Publications are given in four different forms. Published papers are listed in appendix B, and they are referred by author´s name and year. Technical reports are listed in appendix C and are referred by author´s name and report number (73xx-74xx). Master theses finally are referred to as e.g. "RE-141" and are listed in appendix E. There is also a serie of internal reports (73xxC-74xxC) listed in appendix D. They include conference papers to appear elsewhere and also results which are not yet suitable for a wide spread publication.

1. INTRODUCTION

This report is intended to give an overview of the activity in research and education at the Department of Automatic Control. The main thrust of the research is to develop an understanding of control processes, covering system identification, adaptive control, stochastic control theory and system theory. One goal is to develop methods and techniques which will be practically useful. For this reason it is attempted at all times to have projects dealing with practical applications side by side with theoretical development. During the academic year the portion of practical problems was unusually high with major activities in coordinated control of thermal power stations, control of supertankers, control of waste-water treatment plants and control of climate in buildings.

The research has been organized into different projects, most of them supported by the Swedish Board for Technical Development (STU). Except the researchers directly supported by STU, students and staff members of the Department have contributed to the projects.

The projects Control under Uncertainty (Ivar Gustavsson), Computer aided Design (Johan Wieslander), Power Dynamics (Sture Lindahl) and Ship Dynamics and Control (Claes Källström) have been directly supported by STU (The name of the principal investigator within brackets). Within the latter project collaboration has been established with the Swedish State Shipbuilding Experimental Tank (SSPA) and the Kockums Mekaniska Verkstads AB. The Institute of Applied Mathematics (ITM) has partly supported the developments of the interactive simulation program (Hilding Elmqvist) and optimization programs (Torkel Glad). The research on wastewater treatment plants (Gustaf Olsson) has been performed in collaboration with Datema AB and the Käppala Wastewater treatment plant, Stockholm.

The project on Climatized buildings (Lars Jensen) has been supported by the National Swedish Board of Building Research (BFR) and the research on biomedical problems (Per Hagander) by the Swedish Natural Science Research Council (NFR).

The real time computer installation is a powerful tool for most of the research. A combination of software and hardware has been essential for the progress. The computer was used more than 5000 horus during the year.

Even if it is always difficult to keep an appropriate distance to current research it is attempted here to give some comments on the different programs.

We believe that the results on identification of closed loop systems will be of importance because they will make it possible to simplify identification experiments. This is of course of practical value in industrial problems. In economic and biological systems it may be even more important. Broadly speaking we expect the activity in system identification to be focused on special problems and applications. We expect the results on convergence of stochastic algorithms to be very important. They will make it possible to put the analysis of adaptive systems on a firm foundation. It is expected that the activity on adaptive systems will increase. These indications are based on the ease of putting the self-tuning regulators into industrial operation.

It has been demonstrated that the computer aided design programs are of extreme importance as a tool to transfer modern control theory into engineering practice and to make it cost effective. In this respect it is particularly important to make the program packages more easily accessible. This can be achieved by transferring them to the University Computing Center and use them on a time-sharing basis.

2. EDUCATION

The department is engaged in education for the civ.ing. degree, for the PhD degree and in continuing education.

2.1 Civ.ing. program

Five undergraduate courses are given on a regular basis each academic year. These courses are part of an integrated program leading to the degree civ.ing. They serve four different Departments of the Institute of Technology, viz. Applied Physics (F), Electrical Engineering (E), Mechanical Engineering (M) and Chemical Engineering (K). The courses are

- Basic course (allmän kurs)
  Linear continuous time linear systems, both state space and Laplace theory including four laboratory sessions. About 200 students from F, E and M.

- Basic course for Chemical Engineers (mindre kurs)
  Classical control theory applied to chemical processes. About 60 students from K.

- Advanced course (fortsättningskurs)
  Nonlinear systems, linear sampled systems and linear stochastic systems. About 50 students from F and E.

- System techniques (reglerteknik-systemteknik)
  The course is based upon the basic course but is more directed to applications, e.g. computer control, prediction problems, inventory control, boiler control etc. About 30 students from M.

- Computers in control systems (datorer i reglersystem)
  Hardware and software for process control. About 75 students from F, E, M and K.

Some new course material has been developed during the year.

In the basic course the problem book and the problem solutions have been completely revised. The text book is also complemented with some additional study material.

A first version of lecture notes has been completed for the course on computers in control systems.

The courses include lectures problem solving sessions and laboratory. Apart from the ordinary problem solving sessions a special group for interested students has been working in the Basic course. The group has studied a laboratory system consisting of water tanks in series. Model building of the process and the actuators of the real system was made. The model was simulated on analog and digital computers. PID control was tested on the real process. The result is documented in a report (7416 C).

In the System technique course two different project groups have been working on different projects,

- prediction of time series

- control of a steam boiler

- dead-beat control of a heat diffusion process

The results are documented in internal reports (7335 C), (7408 C), and (7421 C).

2.2 Master theses

The degree of civ.ing. (≈MS) requires a thesis work. This thesis (examensarbete) shall prove that the student has learned how to approach and solve larger problems. The work is supposed to take three months of full time work and the work is done by one or two students. During the year 14 theses were finished by 21 students. Abstracts of the theses are presented in a separate report, see Wittenmark (7426). A list of the reports is given in appendix E. All the theses are written in Swedish with an abstract in English.

2.3 PhD program

The graduate program is a four year curriculum leading up to the PhD degree. It is based upon the "civilingenjör" (MS) degree. During about three or four semesters the graduate studies are dominanted by course work. Some of the courses are given as formal lectures, see appendix F. Others are defined by books, lecture notes, tapes, and slides. Due to the small teaching resources also study groups have been organized around different courses, where the students themselves have taken the main responsibility of the studies. Afterwards formal examinations have been organized.

During the academic year there have been 18 active PhD students. Four PhD theses were completed. They are

Per Hagander: Operator factorization and other aspects of the analysis of linear systems (7336), Dec 7, 1973.

Gunnar Bengtsson: A theory for control of linear multivariable systems (7341), Jan 29, 1974.

Ivar Gustavsson: Identification of industrial process dynamics (7402), March 8, 1974.

Lennart Ljung: Stochastic convergence of algorithms for identification and adaptive control (7406), April 26, 1974.

2.4 Control laboratory

A small analog computer has been developed and was finished during the year. It is built with standard modules, which makes it possible to use the amplifiers very feasibly in both education and research. The analog computer contains in a basic version an intrument panel, a signal generator (triangle and square wave), 10 amplifiers (integrators or summators), and two multipliers. There is normal/fast operating speed, repetitive mode as well as sample and hold possibilities. It has been built up in a serie of six machines. The analog computer can be connected to a DC servo system with compensation networks, amplifiers and tacho generator.

A laboratory process, consisting basicly of three tanks in series has been built up. It can be used for level control but will soon be extended for concentration control. The levels of the tanks can be measured. There are two control valves, a flow meter and two PID controllers available. The process has been used mainly in the education.

The computer PDP 15 has been used about 5000 hours during the year, both for real time calculations, remote control and interactive computation.

2.5 Continuing education

The continuing education is considered an important way to transfer research results into practical applications. Several courses and contact meetings between people from industry and the Department have taken place during the year.

In collaboration with the Svenska Teknologföreningen a course "Automatic control - current theory" was arranged for engineers working in industry at May 13-17, 1974. This course have now been given five times and has received great interest from the participants. The course content is presented in appendix G.

A two day course in Process identification was given together with the Liasion Office for Industrial Contacts (Kontaktsekretariatet) at the Lund University at May 29-30, 1974.

About 90 people from industry and research centres participated. The course included 12 seminars (see appendix G). Five of them dealt with theory and seven treated different applications.

The research on self-tuning regulators was presented on an information day on February 14, 1974. There were 79 participants from the industry and other universities. Two contributions on the theory of self-tuning regulators were presented. Half the day was devoted to applications of the self-tuning regulator. The titles are listed in appendix G.

3. SYSTEM IDENTIFICATION

The study of identification problems has given new results on identifiability and accuracy, in particular for systems operating in closed loop. Important results on consistency of prediction error identification methods have been developed. Different types of recursive algorithms have been investigated by a new technique, offering the possibility to study the convergence properties by other means than simulation. In particular it has been shown that a commonly used recursive identification method does not always converge. The problem of common factors in identified models has been studied and an algorithm has been proposed for the solution of the problem. This algorithm also provides a faster way of obtaining the generalized least squares estimate than the usually used algorithm. The work on different identification programs has continued. In particular the interactive program package IDPAC has been brought into a form which has proved to be efficient in many applications, (see 6.2). The research has also resulted in the completion of two Ph.D. theses in 1974, Gustavsson (7402) and Ljung (7406).

Travels and contacts made in connection with the identification research are listed in appendixes F, G and H. Also the course activities should be mentioned, see 2.5.

3.1 Consistency of prediction error methods

An important class of identification methods is based on minimization of the prediction error. The Maximum Likelihood method belongs to this class. In Ljung (7405) the consistency properties of these methods are investigated in a general setting. No specific structures of the models are assumed, and the input signal need not satisfy any conditions on stationarity or independence of the process noise. Hence the results are valid even for systems with various types of feedback mechanisms, including adaptive controllers. The implication for convergence of adaptive regulators are briefly discussed in Ljung (7406) and in Ljung-Wittenmark (7404).

The consistency results are applied to special examples of linear systems such as vector difference equations and state space models. Even for these simple systems correct consistency proofs seem to have been lacking earlier.

3.2 Identifiability properties for systems operating in closed loop

The consistency results mentioned above facilitate a thorough analysis of the identifiability properties for systems operating in closed loop.

Most people working with identification problems have realized the difficulties and fallacies when using data collected during closed loop operation. In Gustavsson-Ljung-Söderström (7401) a comprehensive study of the problems and possibilities is presented. It is shown that in many cases a prediction error method, applied exactly as for open loop systems, disregarding even the existence of a regulator, will give desired results. Furthermore, if this method fails, any other method, even those designed specifically for closed loop systems, will fail. The system is identifiable, e.g. if the regulator is noise-corrupted, time-varying or non-linear or if an extra perturbation signal, added to the feedback signal is used.

In Ljung-Gustavsson-Söderström (1974) some useful identifiability concepts are introduced. The idea of using regulators shifting between simple linear feedback laws in order to obtain identifiability is also introduced.

Accuracy aspects of identification of closed loop systems are considered in Elvgren-Krantz (RE-142) and these problems will be illuminated also in a forthcoming report.

3.3 Recursive stochastic algorithms

Convergence of recursive stochastic algorithms of a general form

$$x_{n+1} = x_n + \gamma_{n+1} H_n(x_n, \varphi_{n+1}) \tag{1}$$

is considered in Ljung (7403) and in Ljung (1974b). It is shown that the asymptotic properties of this algorithm can be studied using the ordinary differential equation (ODE)

$$\dot{x} = f(x) \tag{2}$$

where

$$f(x) = \lim_{n\to\infty} H_n(x, \varphi)$$

Thus, stability of this differential equation together with some additional conditions implies convergence (with probability one) of (1) and the sequence $\{x_n\}$ produced by (1) is related to the trajectories of (2).

3.3.1 Stochastic approximation algorithms

When the results above are applied to stochastic approximation, algorithms like the Robbins-Monro scheme or the Kiefer-

Wolfowitz, convergence results are obtained which are more general than usually reported. Thus, dependent noise sequences can easily be handled and the usual condition

$$\Sigma \gamma_n^2 < \infty$$

can be traded off against conditions on the moments of the noise. Hence more slowly decreasing sequences $\{\gamma_n\}$ can be allowed, which may be advantageous from the viewpoint of convergence rate. In Ljung (1974a) the asymptotic variance for the Robbins-Monro scheme is studied as a function of $\{\gamma_n\}$.

3.3.2 Recursive identification methods

The ODEs corresponding to several different identification methods have been studied in Johannesson-Wesström (RE-140). It has been found that they are a valuable complement to direct simulations of the algorithms. By analysis of the ODE some new facts about the convergence properties have been discovered which will be presented in a forthcoming report. Recursive identification methods are also studied in Åström (1974), where the near connection of these algorithms to the self-tuning regulators is demonstrated. Possible convergence points for the extended least squares method are also given.

Applying the instrumental variable method is a commonly used way of performing recursive identification. Some anlysis of this method has been reported in the literature. In Söderström (paper 1974c) a continued analysis is presented. It is shown that there are unexpected restrictions for suggested methods to work properly.

3.4 Test of common factors

In the analysis of models obtained by process identification it is often desirable to test for common factors. A typical example is models of multivariable systems where the number of common factors may have a drastic influence on the final choice of order as well as on the structure of the model. The problem of performing tests of common factors when the uncertainties of the polynomial coefficients have to be considered is treated in Söderström (7328). A systematic way to carry out the tests is suggested. It is shown that applied to the least squares model it is nothing but a new very efficient way of computing the generalized least squares estimate. In Söderström (7328 C) an alternative method based on the Euclidean algorithm is considered. This method is proved to give consistent estimates if the input is white noise. However, it does not in general provide a suitable estimate of the order of the system.

3.5 Suboptimal filtering for real time identification

The work reported in previous annual report on suboptimal filtering has resulted in a report.

In Olsson-Holst (7324) approximative filters, used to track unknown parameters in linear multivariable systems are examined mainly from a computational point of view. Three different filters, all based on Extended Kalman Filtering, are compared and tested, an Extended Kalman predictor, an Extended Kalman filter and a Single State Iteration Filter.

Two aspects are emphasized in the report, filter consistency and filter convergence. For a special first order case, filter convergence can be analytically established and numerically confirmed.

3.6 Applications

The available programs for identification and process parameter estimation have been used extensively for modelling of a great number of processes. In particular the interactive program IDPAC (see 6.2) has been used. In the following the most important applications are reviewed briefly. The applications are described more in detail in chapter 8.

A nonlinear model of a reheat boiler-turbine unit, suitable for power system studies, has been developed. The model consists of two first order differential equations. The state variables are drum and reheater pressure. The input signals are control valve position, fuel flow and feedwater flow. The primary output variable is the active power. Numerical values of the uncertain parameters were estimated from the experimental data collected at Öresundsverket in Malmö in 1969.

Measurements on tankers have been performed in cooporation with Kockums Mekaniska Verkstad, Malmö. Some of them have been used for determination of models of ship dynamics in the joint project between the Department and Kockums Mekaniska Verkstad.

Dynamic models of processes in waste water treatment plants have been developed. Two master theses have been completed, Gutman-Olsson (RE-136) and Larsson-Schröder (RE-146).

Within the environmental area also river pollution models have been identified. The dynamics of algal populations and their interaction with the dissolved oxygen and biochemical oxygen demand in a freshwater stream has been identified.

For the interior climate application identification is used as a standard tool for developing dynamic models for different processes involved. The identified models have also been compared to models based on physical laws and construction data.

The cooporation with B. Häggman at the STFI (Svenska Träforskningsinstitutet), Stockholm has continued. Identification has been used for the evaluation of existing basis weight and moisture control of an industrial paper-machine.

Different biomedical systems have been modelled via identification. In particular the respiratory system has been studied using a program for identification of nonlinear models. This work was carried out together with Prof. G. Swanson, UCLA, Los Angeles, California, USA. Also other nontechnical systems have been studied. In Hedenström (RE-135) a simple monetary model of the Swedish economy is presented. In Hylander (RE-137) an attempt is made to develop a model between the educational and labour markets.

4. ADAPTIVE CONTROL

The research on adaptive control sysems has been concentrated on the areas:

- convergence analysis for adaptive controllers
- analysis of self-tuning regulators for non-minimum phase systems
- self-tuning regulators for multivariable systems

The research on self-tuning regulators was presented on an information day, see 2.5.

4.1 Convergence analysis for adaptive controllers

It is generally very difficult to analyze the convergence properties for different adaptive controllers. This is due to the facts that the systems are working in closed loop and that there are stochastic disturbances acting on the systems. A new tool has, however, been developed which makes it possible to analyse the convergence properties of different adaptive controllers, see 3.3. The application of the techique to self-tuning regulators is described in Ljung-Wittenmark (7404) and Ljung-Wittenmark (1974). In these reports are considered adaptive regulators for stochastic systems where the unknown parameters in the regulator are estimated using a recursive identification algorithm. It is shown that the expected trajectories of the parameter estimates are described by a set of nonlinear ordinary differential equations. The convergence points for the adaptive controller are the same as the stable stationary points of the differnetial equations. It is thus possible to find the possible convergence points and to analyze the stability of the adaptive controller. In most cases it is difficult to analyze the differential equations, but numerical simulation and linearization can be used to carry through the investigation.

Using the expected trajectories it has been possible to study how different identification algorithms and structures of the regulator influence the convergence properties of the closed loop systems.

It is also possible to show that the basic self-tuning regulators, under weak conditions, have a strong stabilizing property. This means that the self-tuning regulators make the closed loop system stable, even if the estimation does not converge.

4.2 Dual control

For systems with constant but unknown parameters there are several efficient methods for contemporary identification and regulation. In the case of time-varying parameters, however, these methods may be poor, and therefore other algorithms are needed.

It is very difficult to calculate the optimal regulator for systems with stochastically time-varying parameters, and only in a few simple special cases it has been numerically computed.

A system, described by a governed Markov chain with four states, has been considered by Jan Sternby. The transition probabilities are piece noisely linear-functions of the input variable. At At each moment a measurement is made to update the information about the state. A loss function is introduced, and the regulator is chosen to minimize the expected value of the loss.

This problem has been solved explicitly. Different types of suboptimal strategies are compared (analytically) with the optimal one in terms of the loss function.

It is, of course, not clear how the results for this special system apply to the more general case the fact however, that an analytical solution is given interesting since it makes it possible to compare different strategies. Therefore more insight into the problem is gained.

4.3 Self-tuning regulators for non-minimum phase systems

A self-tuning regulator for non-minimum phase systems is described in Åström (7411(C)). The regulator, STURE2, estimates the parametes in a model of the process using the method of least squares. The regulator is then determined by minimizing the variance of the output under the constraint that the closed loop system is stable. This is done by solving a Riccati equation in each step of time.

The properties of the regulator STURE2 are analyzed in Åström-Wittenmark (1974). It is shown that the regulator in same cases converges to the optimal regulator that could be obtained for known parameters. In other cases the regulator might converge to an other solution or not converge at all. The stationary points of the regulator depends on the structure of the process and the controller as well as on the values of the coefficients in the process.

An other variant of a self-tuning regulator is decribed in the MS thesis Bengtsson-Egardt (RE-141), where the identification is done using an approximative real-time Maximum Likelihood method. The report also describes a command driven program for simulation of different self-tuning regulators.

4.4 Self-tuning regulators for multivariable systems

Self-tuning control of multivariable systems has also been studied during the year, mainly by Ulf Borisson. The controlled system is described by polynomial matrices satisfying certain conditions. Recursive least squares identification is used for the estimation of the regulator parameters. The disturbances acting on the system are described as a moving average of white noise. The criterion of the control is to minimize $Ey^T(t)\ Q\ y(t)$, where y is the output vector an Q is a positive semidefinite matrix.

Simulations of the algorithm have given good results. The lack of a unique representation of the optimal regulator in the multivariable case makes the analysis more complicated than in the single-input single-output case. Under certain assumptions concerning the structure of the controlled system it can, however, be shown theoretically that the algorithm has the self-tuning property.

4.5 Applications of self-tuning regulators

It has earlier been reported that the self-tuning regulator has been used for control of a paper machine and an ore crusher. The paper machine experiments are described in detail in Borisson-Wittenmark(7337) and The feasibility study of self-tuning regulators sponsored by STU is summarized in Alsholm,-Borisson,-Stavnes-Wittenmark (7338). The applications have also been reported on various conferences, Wittenmark (1974) and Borisson-Syding (1974).

The self-tuning regulators have also been used to control oil tankers (see 8.2) and an entalpy exchanger (see 8.4). An overview of the theory of self-tuning regulators and their application are given i Åström(7417(C)).

4.6 Adaptive prediction

The research on self-tuning regulators has also resulted in methods for adaptive prediction. These as well as other prediction methods for one dimensional time series have been studied.

In order to get some insight in the properties of some other, often used, prediction algorithms one master thesis, Casenberg-Sandberg (RE-139), and one project work (7335(C)) have been devoted to prediction of some different data series. The work shows the advantages of real-time methods and methods which take special, â priori known, features of the data into consideration. One such method is the adaptive predictor.

In the adaptive predictor the problem of real-time prediction is separated in two. Firstly, the parameters of the process, which are assumed to be constant, are identified using the least squares method of identification and secondly the process is predicted as if the estimated paramters were the true ones.

If the parameter estimates converge and if the predictor contains enough parameters, they converge to the minimum square error predictor that could be obtained if the parameters of the process were known.

This adaptive predictor can be used to predict processes which contain trends or periodic variations. Also processes with slowly time-varying parameters can be handled by the algorithm after only slight modifications.

The computational requirements at every sampling interval are very moderate.

The predictor has been applied on real data series, for example natural gas disposition and number of passangers on international airlines, see figure 1.

The predictor is discussed in Wittenmark (1974). It has also been presented at different seminars, see appendix G.

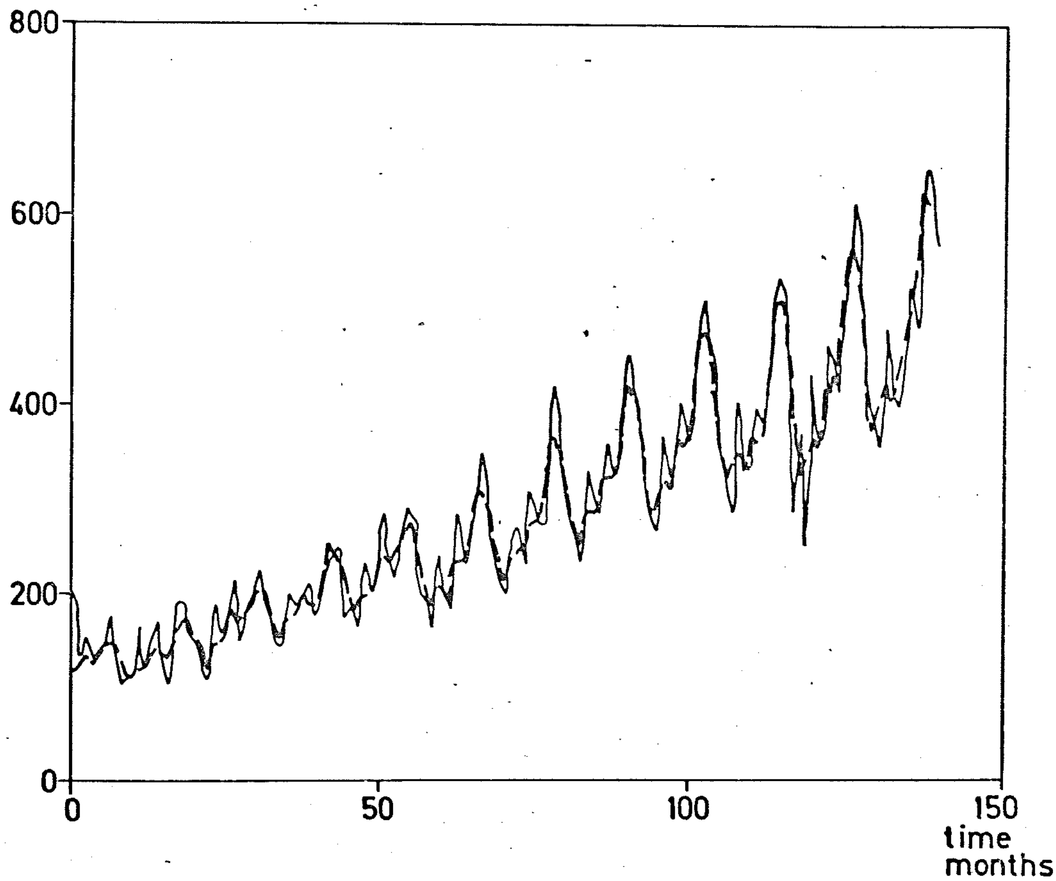

Fig 1. The predicted and the actual value of the number of passengers on international airlines 1949-1960 (data from Brown, R.G. Smoothing, Forecasting and Prediction of Discrete Timeseries, Prentice-Hall, 1962).

5. COMPUTATIONAL CONTROL

The work on optimal control of a sulfite cooking process which was presented in last annual report has now been published in Hagberg-Schöön-Ljung-Mårtensson (1974).

In optimal control of nonlinear systems no â priori structure is given to the controller in the general case. In order to save computing time one can assume a given structure of the controller, and the optimization problem is limited to the problem of finding minimum of a function of a finite number of variables. This is described in 5.1. The program library is discussed in 5.2.

5.1 Constrained minimization and its application to the design of control systems

The following problem has been considered

$$\text{minimize } f(x)$$
$$\text{subject to } h(x)=0 \qquad g(x)\leqslant 0$$

This problem can be converted into an unconstrained one by using the function

$$F(x,\ \mu,\ \lambda)=\ f(x)+\mu^T h(x)+\frac{c}{2}\ h(x)^T h(x)+\Sigma\frac{1}{2c}[(c\ g_i(x)+\lambda_i)_+^2-\lambda_i^2]$$

For a certain choice of μ and λ this function has a local minimum at the point x which solves the original problem. The solution can be found by successive minimizations of $F(x,\mu,\lambda)$. After each minimization μ and λ are updated using the formula

$$\begin{pmatrix} h_x \\ \tilde{g}_x \end{pmatrix} B \begin{pmatrix} h_x^T & \tilde{g}_x^T \end{pmatrix} \begin{pmatrix} \delta\mu \\ \delta\tilde{\lambda} \end{pmatrix} = -\begin{pmatrix} h \\ \tilde{g} \end{pmatrix}$$

where ˜ denotes the active inequality constraints and B is an approximation of the second derivative of F. The possibility of updating μ and λ more often has been studied. The problem is that divergence can occur in some cases. To prevent this a criterion

$t=||(L_x, h_1, \ldots, h_m, \min(\lambda_1, -g_1), \ldots)||$ can be used. If this criterion decreases each time μ and λ are updated, convergence can be guaranteed.

The optimization algorithms have been used in a program for interactive design of nonlinear control systems. The process can be described by differential equations, $\dot{x}=f(x,u)$ or difference equations $x(t+T)=f(x(t), u(t))$. A control law of the form $u=k(x)$ is then to be found. A control law of fixed structure but with certain unknown parameters p is assumed, i.e. $u=k(x,p)$. A suitable performance criterion is chosen and constraints (if any) are specified. Then the control problem is solved by using the function minimization algorithm to adjust p.

The implementation has been done by adding the optimization routine to an already existing interactive simulation program, SIMNON, (see 6.3). This means that the response of the system is displayed for each value of p which is tried by the algorithm. The method is quite general - any combination of system, criterion and constraints, which gives a well defined optimization problem, can be treated.

5.2 Program library

Most of the programming efforts during the year have been directed to development of interactive programs, see chapter 6. Possibilities to transfer the programs to the Univac 1108 at Lund Data Center have been explored because such a transfer will increase the availability of the programs for external users.

With the Exec 8 operating system at the Univac computer, time sharing has been possible to a larger extent. A teletype terminal has been installed, which has simplified the computational work considerably.

The programs have been used by external users. The ML identification program package was used by SAAB, Linköping from the terminal at Linköping University. Also other industries and research centers have shown an increasing interest in using program packages from terminals.

The program package on UNIVAC 1108 for parameter estimation in linear state space models has been used in particular in the project for determination of ship dynamics. It has been developed into a form which both allows for solving very general identification problems and for effective use. This program has been used by SSPA in Gothenburg by tele processing. The program for identification of nonlinear models has been used for developing a model for a reheat boiler-turbine unit and for determination of models of different biological processes. For that purpose the program has been revised in order to accept data with non-uniform sampling rate.

6. COMPUTER AIDED DESIGN

In this project the purpose is to transfer results and methods of modern control theory into a form suitable for use in applications. The main tool for this work is then interactive programs of a command type. The program can be considered as written in a high level language for the solution of control design problems. By such a tool a considerable simplification is achieved to make use of complicated methods.

6.1 Structure of the interactive programs

The interactive programs which have been developed are primarily aimed for the advanced user. It is assumed that he knows what to do and that he is familiar with the methods. This may be the normal situation when the programs are applied in a professional environment, at a university or in an industry.

With this philosophy in mind the programs are controlled by commands. This gives a complete freedom in the program flow. On the other hand it does not give the beginner any advice how to proceed.

Earlier there was a possibility to build up a sequence of commands into a new command. Then it was possible to more effectively use the commands in special situations. This MACRO facility has been further developed. It now can include jumps and iterations and even questions and orders to the user.

By this extension of the MACRO facility it is possible to write programs in the language which have been implemented in the programs IDPAC and SYNPAC (see 6.2). The programs then can be made question controlled, which is advantageous if the user is a beginner. Especially in the education it is important.

The new MACRO facility is also used in the program system SIMNON (see 6.3) for nonlinear system simulation.

6.2 Interactive programs for identification(IDPAC) and synthesis (SYNPAC)

The program IDPAC for interactive datahandling and identification was first reported in last annual report. It has been further developed and extended. The data handling routines include data moving, scaling, trend estimation, filtering etc. The estimation algorithms contain Maximum Likelihood estimation of multiple-input-single-output systems, correlation analysis, model analysis as well as statistical tests.

At present the program system is used daily by many different researchers, and no known errors exist. Corrections and adjustments are made succesively but no major change or extension is beeing planned.

The program has been transferred to the Department of Applied Electronics (Tillämpad elektronik) at the Chalmers Institute of Technolgy, Göteborg. In Gustavsson-Selander-Wieslander (7331) a detailed user´s guide is written.

For synthesis of multivariable linear systems some new interesting results have been developed during the last year, see 7.1 and Bengtsson (7341, 1974a, 1974b) and Bengtsson-Lindahl (1974). The work to implement these ideas in the interactive program SYNPAC for control synthesis has just started.

The SYNPAC program package has now been in use at the Department for two years. The command structure will now be improved to the same advanced level as in IDPAC. Some planned extensions are presently being implemented.

The ideas about the interactive programs have been presented at international conferences in reports, see e.g. Wieslander et al (1974) and Bengtsson (1974a).

At meetings in Lund the programs SYNPAC and IDPAC have been in frequent use, e.g. at the identification meeting at May 29-30, the control course at May 13-17, see appendix G.

6.3 Interactive program for simulation of nonlinear systems (SIMNON)

The first version of SIMNON was developed as a master thesis in 1972. The program has during the year been largely extended. It is in frequent use at the Department and has also been moved to the Dec-10 system at the Stockholm Data-Center. Below is given a short description of the new version of SIMNON and also an example of how to use the program.

SIMNON is a command driven interactive program written in FORTRAN for the simulation of systems governed by ordinary differential equations or/and difference equations.

The basic set of commands allows the user to
- define the system;
- change parameter values;
- change initial values of dependent variables;
- perform simulation;
- select variables for plotting;
- draw axes

Systems can be described either in a special simulation language or in FORTRAN. The program has a built-in compiler for the simulation language and to get high interactivity when changing the system structure there is also an editor included. The simulation language consists of

declarations for time, state, derivatives, etc.;
ALGOL:s assignment statement for the assignment of derivatives, variables, etc.;
a special statement for the assignment of parameters and initial values

It is possible in SIMNON to define subsystems, with inputs and outputs, separately and then connecting them. Each subsystem could be described either by ordinary differential equations or difference equations.

Example

Consider the system

$$x_1(t)=-4x_1(t)-3x_2(t)+u(t) \qquad x_1(0)=0$$

$$x_2(t)=x_1(t) \qquad x_2(0)=-1$$

$$y(t)=x_2(t)$$

and the discrete control law

$$u(t_i)=l_1x_1(t_i)+l_2x_2(t_i) \qquad i=1,2,\ldots$$

with

$$t_{i+1}=t_i+0.1 \; ; \quad t_1=0$$

and

$$u(t)=u(t_i) \qquad t_1<t<t_{i+1}$$

The system has been simulated for different values of l_1 and l_2. The system description, the command sequence and the plotted results are shown on next page.

28.

```
CONTINUOUS SYSTEM S

INPUT U
OUTPUT Y
STATE X1 X2
DER DX1 DX2

OUTPUT
Y=B1*X1+B2*X2

DYNAMICS
DX1=-A1*X1-A2*X2+U
DX2=X1

A1:1
A2:1
B1:0
B2:1

END

- - - - - - - - - - - - - - - - - -

DISCRETE SYSTEM L

INPUT U1 U2
OUTPUT Y
TSAMP TS
TIME T

OUTPUT
Y=L1*U1+L2*U2
TS=T+DT

DT:1
L1:0
L2:0

END

- - - - - - - - - - - - - - - - - -

CONNECTING SYSTEM CONN

U1[L]=X1[S]
U2[L]=X2[S]
U[S]=Y[L]

END
```

```
>SYST S L CONN
>LIST S L CONN - LP
>
>PAR A1:4
>PAR A2:3
>PAR B2:6
>PAR DT:Ø.1
>INIT X2:-1
>
>PLOT U Y[S]
>AXES H Ø 3 V -8 6
>SIMU Ø 3 - MARK
>DISP A1 A2 B1 B2 DT
>MACRO DIS
  >DISP L1 L2
  >CLOSE
>
>PAR L2:-10
>AXES
>SIMU - MARK
>DIS
>
>PAR L1:-2
>AXES
>SIMU - MARK
>DIS
>
```

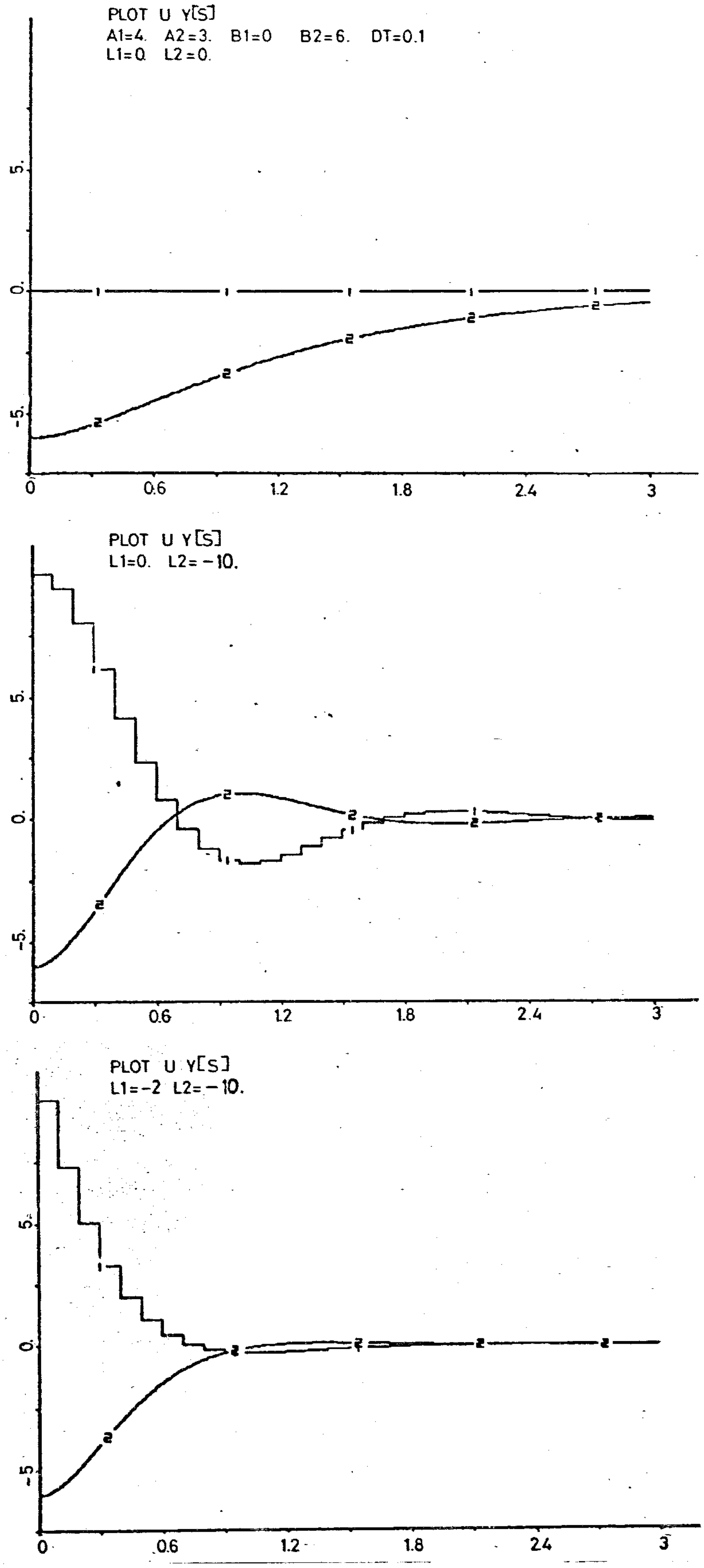

Fig 2. Typical system descriptions, command sequence and resulting plottings in SIMNON.

6.4 Classical Design Program Package (CDP)

The coopreation with other universities has resulted in exchange of programs. From the Department for Computing and Control at Imperial College, London, an Interactive Classical Design Program Package (CDP) has been received.

It is possible to consider linear, time-invariant, single-input-single-output systems in continuous or in discrete time.

The rootlocus, Bode, Nyqvist and Nichols diagrams as well as step responses can be calculated and plotted. Stability analysis can be performed with the Routh algorithms. The system can be represented as a transfer function, with poles and zeroes or in state space form. Transformations between these representations can be made.

The CDP has been transferred to the PDP 15 computer at the Department. The plot routines had to be rewritten and the output formats had to be modified. Some minor exclusions were also made.

7. SYSTEM THEORY

Within the graduate program research is going on in system theory. The activities can be split up into two areas, multivariable system theory and distributed parameter systems.

The results in multivariable theory will be transferred into the program package SYNPAC, as remarked in 6.2.

7.1 Multivariable systems

7.1.1 Time optimal control

The problem of driving the output or the whole state of a linear time-invariant multivariable discrete system, with an arbitrary initial state, to the origin, in a minimum number of time units, is considered. The goal should be accomplished by a linear feedback, possibly time-varying, from the state variables. The following types of controllers are considered

state time-optimal controllers
output time-optimal controllers
minimum gain time-optimal controllers

The controllers can be used to drive the output of a system, with an arbitrary initial point, to any stationary point of the process, i.e. to perform a production change in minimal time. The controllers have been extensively used to control the profile of a heat diffusion process, see further 8.5.

7.1.2 Control of linear systems

The work on the servo and regulator problems for linear time-invariant multivariable systems has resulted in a PhD thesis, see Bengtsson (report 7341).

The inverse system concept has been considered in detail and algorithms are proposed for the numerical computation of them. For the servo problem it is essential to compute such system inverses in order to achieve a proper control structure. Some results are published in Bengtsson (1974 a) and in a conference paper, Bengtsson (1974 b).

In the regulator problem area the restricted feedback problem has been considered. The idea is to restrict the complexity of the feedback structure of the regulator. This means that only output signal or a subset of the output signals can be used as feedbacks in the controller. These results are published in Bengtsson-Lindahl (1974) and are presently being implemented in the program system SYNPAC.

7.2 Operator Formulation of Linear System Theory

The work on the operator formulation of linear dynamic systems has resulted in a PhD thesis, Hagander (7336). The continuous time results are published in Hagander (1973), while the discrete time results appear in Hagander (7330). A thorough treatment of the start up of a Kalman filter for a system with totally unknown initial state, is given in Hagander (7332). The optimal recursive filter could be described as a minimal variance dead beat filter. The continuous time systems become observable after an infinitely short time, and a filter could be started from an initial estimate, but the corresponding Riccati equation is ill conditioned. Instead it is described how to use two parallel filters until the error covariance is reasonable.

7.3 Distributed parameter systems

The Operator Riccati Equation (ORE), associated with optimal control and optimal filtering problems for linear distributed parameter systems has been considered.

If, for the control problem, there is only a finite number of outputs that are penalized in the quadratic criterion, and a finite number of inputs, then the ORE can be reduced to simpler equations. The ORE is a partial differential equation (PDE) in one time variable and two space variables, while the reduced equation is a PDE in one time variable and just one space variable. This will in general lead to considerable savings in computing time when the equations are solved.

In Casti-Ljung (7344 and 1974) the general distributed control problem is treated and in Ljung-Casti (1974) a case with boundary control is considered.

8. APPLICATIONS

A number of different applications of identification theory, adaptive controllers and computer aided design are reported below.

8.1 Power Systems (Sture Lindahl)

The activities has been concentrated on two problems:

modeling and control of a thermal power plant
modeling and control of an industrial gas turbine

8.1.1 Coordinated control of a thermal power plant

The task of the controller is to:
1) perform a rapid increase of output power in the case of network disturbances, 2) increase the damping of network oscillations, and 3) adjust active power and excitation current in order to keep network frequency and terminal voltage at their reference values.

The project was introduced to some representatives for the power industry on 1973-09-05, see Lindahl(7326 C). It was pointed out that the steam turbine, in contrast to the hydro turbine, is a minimum phase system and suitable for rapid changes of output power. Moreover the terminal voltage can be used only to increase the damping of network oscillations. Attention was also drawn to the fact that a commercial product must contain equipment for the protection of the plant.

Preliminary simulations has shown, that it is adequate to use a simplified model of the steam turbine. With this model however, it was not possible to study important variables in the thermal power plant, e.g. drum level, drum pressure and steam temperatures. A literature survey indicated that constant pressure control gives the most rapid changes of output power. Sliding pressure control gives slow responses but better economy than constant pressure control. It was concluded that it was desirable to use some form of modified sliding pressure control. Then the plant can be run with low specific fuel consumption. There are also possibilities to increase the output power in emergency situations.

In order to study the control during disturbances a detailed model of the thermal power plant has been developed. The basic equations were given by Eklund (report 7117). The equations are modified to the experiments performed on Öresundsverket, P1G-G16, also described by Eklund. The interactive simulation program SIMNON is used to simulate the model.

A coordinated controller is designed using ideas in Bengtsson-Lindahl (1974). The controller is designed to receive a power demand signal from a central network controller. The received power demand signal is modified by the local controller in order to protect the plant. The power reference signal is formed by an jump-and-rate-circuit. The controller adusts control valve, fuel flow, feedwater flow, and attemperator flows in order to control output power, drum pressure, drum level, and steam temperatures. The controller operates in one of two modes: 1) normal mode or 2) alert mode. In normal mode the power jump is 10% and power rate is 9% per minute. In alert mode the power jump is 15% and the power rate is 12% per minute. When the output power is changed from 65% to 100% the drum level is within $\pm$ 7cm and final steam temperature is within $\pm$ 4^{o}C.

8.1.2 Models and control of an industrial gas turbine

The experiments performed on an 70 MW industrial gas turbine in Halmstad carried out in cooporation with Sydsvenska Kraft AB and STAL-LAVAL has been followed up with a MS thesis by G. Andersson.The work has been directed towards control of the gas turbine but started with model building from basic physical laws. By great assistance of Mr. R. Bränström and Mr. L. Ljung both with STAL-LAVAL, crucial information was obtained about the characteristics of the compressors and turbines. The responses of the simulation model was compared with the measurements obtained in Halmstad and showed good fit.

A nonlinear controller was designed using ideas in Bengtsson-Lindahl (1974). The performance of the controller was investigated by extensive simulation in SIMNON. The simulated responses of the designed controller showed an indeniable improvement compared with the measured responses of the existing controller. The work has been presented to STAL-LAVAL and Sydsvenska Kraft AB.

8.1.3 State estimation in power networks

The problem of state estimation has been studied during the year by A.J.M. Overbeek as a partial fulfillment of the requirements for the MS degree in Electrical Engineering at the Eindhoven University, Eindhoven, the Netherlands.

In Overbeek (7331 C) a literature study is made on state estimation in power networks. The estimation methods have been classified and are split up into three different categories,

- weighted least squares method, according to Schweppe
- sequential processing of measurements with relinearization after each measurement
- a method which first computes linevoltages from lineflow measurements and considers these as new measurement variables

8.2 Ship Dynamics and Control

In collaboration with SSPA (The Swedish State Shipbuilding Experimental Tank) process identification techniques have been applied to determine ship dynamics. The program package for parameter estimation in linear state space models, described in the last annual report, has been improved. The program package has been used to analyse measurements from two different cargo ships and from two 255 000 dwt oil tankers. The measurements of the tankers were performed in collaboration with Kockums Mekaniska Verkstads AB and the Salén Group.

A joint project with Kockums Mekaniska Verkstads AB to design an adaptive autopilot for large oil tankers started 1973-07-01. The purpose of the autopilot is to keep the ship on the desired course and to perform course changes in different speeds and load conditions, and when the ship is disturbed by wind and waves. Preliminary experiments with a basic self-tuning regulator have been performed on the tanker Sea Scout, owned by the Salén Group. The course error was minimized by the regulator and the yaw angular velocity was used as a feed-forwars signal to improve the course keeping. The regulator was quite capable to perform a good course keeping, and further experiments with an adaptive autopilot containing a basic self-tuning regulator will be carried out.

A ship simulation program has been developed on the PDP 15, using the interactive simulation package SIMNON. A nonlinear mathematical model of ship dynamics has been received from SSPA, and a simple model of disturbances from wind and waves has been added. The ship simulation program is used to test different kinds of autopilots and to prepare full-scale experiments of ships.

8.3 Environmental problems

Two different areas of environmental control are fields for research. One is control of wastewater treatment plants and the other is modeling of river quality.

8.3.1 Wastewater treatment (G. Olsson)

The feasibility study on control of wastewater treatment plants, reported in last annual report was finished during the fall of 1973. It has been reported in Olsson-Dahlqvist-Eklund-Ulmgren (7342).

In early 1974 the next stage of the work was started up. Hitherto the emphasis has been devoted to dynamic models and control of the activated sludge process. Experiments were started up during the fall of 1974 and model building and identification works are still dominating the activity. The experiments are performed at the Käppala wastewater treatment plant in Stockholm in cooperation with Datema AB, Nynäshamn.

During the year two MS theses have been performed, Gutman-Olsson (RE-136) made a literature study and also identification on experimental data from the Sjölunda wastewater pilot plan in Malmö as well as from Palo Alto municipal treatment plant in California, USA.

In another MS thesis by G. Schröder - R. Larsson a dynamical model of sedimentation tanks has been derived and simulated. The report is under preparation.

8.3.2 Urban sewer flow dynamics (B. Beck)

Unlike many process industries wastewater treatment plants receive a crude input material under widely varying conditions of quantity and quality. The preliminary findings of the study of activated-sludge dynamics (see above) indicate significant possibilities for improved process control in the event that influent characteristics can be predicted for a wastewater treatment plant.

Rainfall data for Stockholm and surroundings as well as sewer flow data for the Käppala wastewater treatment has been collacted. Different predictors which can estimate parameters in both rainfall/sewer flow relationships and dry weather flow diurnal patterns will be investigated.

8.3.3 River quality dynamics (B. Beck)

This project concerns studies in progress both in Lund and in the Control Engineering Group at Cambridge University, England. Identification of the dynamics of algal populations and their interaction with the dissolved oxygen (DO) and biochemical oxygen demand (BOD) in a fresh-water stream has been performed. The basic state space model for DO-BOD interaction and the initial verification thereof is reported in Beck-Young (1974); further identification studies using the extended Kalman filter, which are described more fully in a coming paper, are summarized together with the description of analyses for in-stream DO level feedback control in Young-Beck (1974). The general area of control theory application in problems of water quality maintenance is reviewed in Beck (7402(C)).

While DO-BOD interaction is comparatively well understood, the relationships between algal populations and the DO and BOD require further examination. Using the program packages for maximun likelihood estimation of both black-box (IDPAC) and state space (LISPID) models it is possible to interpret the results for the synthesis of a combined DO-BOD-algale model, see Beck (1974). The growth and decay of the algal population are represented in terms analogous to those for the culture of microorganisms in the biological processes of wastewater treatment, see e.g. Olsson et al (7342).

Aspects of the maximum likelihood identification results are enlarged upon in Beck (7431(C)); the data relate to a section of the River Cam in eastern England.

8.4 Climatized buildings (L. Jensen)

This project is supported from the National Board of Building Research and has been reported in earlier reports. During the year eight research reports have been completed.

Some identification experiments have been carried out with an airconditioning plant and a connected lecture room using a process computer. The purpose of the work was to get models of the process suitable when designing a regulator. Different discrete time single input and single output models have been identified from data. The sampling interval was one minute. The models turn out to be of first and second order. The results are reported in Ekström-Hänsel-Jensen-Ljung (7408).

Digital control of the air conditioning plant has then been reported in Ekström-Hänsel-Jensen-Ljung (7409). Using a process computer different control laws have been tested. The work showed that control laws based on models of the plant had better performance than conventional ones. The work also showed that the models, which were based on identification experiment, are capable of predicting the closed loop behaviour of the control system very well.

In figure 3 it is shown results from some experiment with controllers of different complexity on the system. Implementations using a conventional proportional valve with a positioner, as well as using an on/off magnetic valve have been tested and compared.

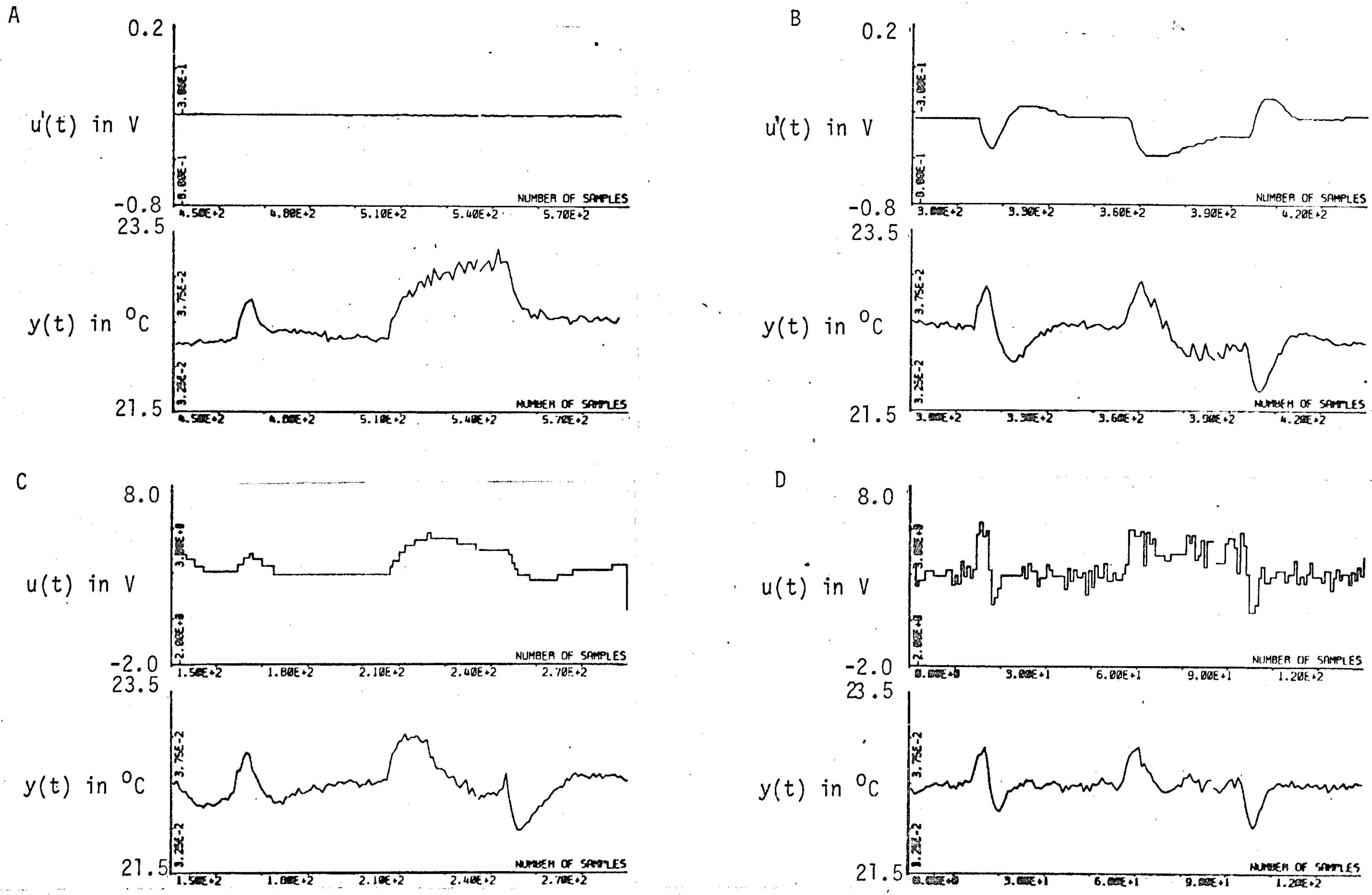

Fig 3. Climate control.
Full scale experiments with a heat load of 2 kW. $u(t)$ is the control signal in volts and $u'(t)$ is the position of the valve in volts ($u'(t) \approx -0.1\, u(t)$). $y(t)$ is the air temperature after the room in ^{o}C.

A Open loop
B An analog PI regulator
C A computer PI regulator (1)
D A linear quadratic regulator (6)

Different methods to derive dynamic models for the input output system heated airtemperature to roomair-temperature for a fullscale test room have been compared. One method is to use construcion data and a simple first order heatbalance equation. The other method is to identify model parameters from experimental data. The parameters computed from construction data differs about 30% from the identified parameters for a first order model. The results are shown in Jensen (7412).

A comparison is made between simulated, and fullscale experiments of on/off control of roomair temperature. The results show that the models describe the process well, see Jensen (7413).

Dynamic systems with recirculation can be described with difference-differential equations. These equations are in most cases impossible to solve analytically. An approximation is made for a given system. A comparison is also made with real data from an air-conditioning plant. The main behaviour is well described by the approximation. The work is reported in Jensen (7414).

Simple first order models for electrical heating devices have been developed from construction data, see Jensen (7415). These models are compared with models identified from data from especially made experiments. The main time constants and the static gains are roughly the same for the models derived in two different ways, see Jensen (7415).

On/off control uses normally only the sign of the output. If the output and its derivative are used together the on/off control can be improved for a first order system with time delay. The improved control is tested in a fullscale process with good result. The experiments are described in Jensen (7416).

An enthalpy exchanger has been studied as a temperature exchanger in Jensen-Hänsel (7417). Static and dynamic models based on construction data have been developed. Static and dynamic models have also been derived from experimental data. The process is highly nonlinear which is reflected in the models. The static gain varies with a factor about 100. The dynamics is rather fast. A controller with fix parameters will have a bad performance. A simple self-tuning regulator is implemented and tested in fullscale experiments with good result.

8.5 Profile control of a heat diffusion process (B. Leden)

The process is a pilot plant in the laboratory and consists of a long copper rod. The inputs of the process are the end temperatures of the rod and the outputs are the temperatures in seven equidistant points along the rod. The process is accurately modelled by a one-dimensional heat equation.

Control strategies have been constructed which take the profile of the rod, from an arbitrary initial profile, to a stationary profile, i.e. the temperature of the profile varies linearly with the space-coordinate. The number of measured process outputs are varied from one experiment to another and the state of the process is reconstructed using Kalman filters, based on the available information. The reconstructed state vector is fed into the controller and a linear feedback from the reconstructed state variables is formed. The calculations of the control strategies and the Kalman filters are based on lumped models of the diffusion process.

It turns out that knowledge of the end temperatures of the rod is enough to obtain satisfactory profile control and that additional information, obtained by measuring the temperature in some points along the rod, only slightly increases the performance of the controller. This result is encouraging because, in a practical situation, it is often possible only to measure the boundary temperatures of a heat process.

There exists a contradiction between the requirement of a fast settlement of the profile and small control signal amplitudes. The boundary temperatures are restricted to take values which slightly exceed the maximum value of the terminal profile. If a minimum - time controller is used to get a certain temperature profile there is a significant saving of time compared to the uncontrolled case.

8.6 Biomedical problems (P. Hagander)

One Master thesis Nerman - Perby (RE-132) was finished during the year. An interactive simulation model for the respiratory system was developed based on a model by civ.ing. B Koch, SAAB. The model is expanded to describe the long mechanics as well as the gas concentrations and the control. The system requires differential-difference equations. The need for general simulation packages also for such systems became obvious, and the SIMNON package at the Department has later been extended.

The feasibility study on renal clearence together with Clinical Physiology, Lund was finished during the fall. It ended in a number of questions: The tentative model for the distribution of Cr-EDTA obtained from impulse experiments was probably too simple and did not contain the longest time constants, which became significant in steady state. This means, that the attempt to control to steady state and then assume, that input is equal to output, failed because of a long equilibration time partly due to the constraint to only positive inputs. The measurement limitations for a reasonable set up are also serious. The work is documented in Hagander et al (7425 C).

A project together with the Department for experimental surgery in Malmö has started. By controlling the blood flow to certain organs like the liver during cancer-chemotherapy the drug concentration in plasma can be kept low although the concentration in the organ is fairly high. Experiments with dogs are currently going an, and Xe-clearence studies show promising results.

During the spring the work has been done in the US. One month was spent in Tucson with prof. Gross on the application of microcirculation and pharmacokinetics for cancertherapy and five months at UCLA working in a project between Anesthesiology and Systems Science on the control of respiration. Identification of nonlinear dynamic systems has been used as a tool to describe the effect of drugs on the control systems.

8.7 Micro computers (L. Andersson)

A project on micro computers for process control has been started. A simple operator's panel and process interface has been developed for a commercially available micro computer system, the TRANSDATA 7260 series from Transintro AB. Some process control programs have been written. In order to facilitate the programming of the micro computer, some programs have been developed which make it possible to assemble and relocate programs for the micro computer using the PDP-15 as a host computer.

8.8 Economical and social systems

In a MS thesis a dynamical model has been developed for the relationship between education and labor market, see Hylander (RE-137). A considerable part of the study consists of a discussion on the conceptualization of the problem, basic assumptions, model limitations and the availability of data needed.

Parameter estimations have been performed with the program IDPAC. The estimated parameters are included in a system of difference equations with 6 outputs and 10 inputs. The study should be considered as a first attempt to apply control theory to this type of problems.

A simple monetary model of the Swedish economy has been identified in a MS thesis by Hedenström (RE-135). The relationship between monetary and fiscal actions, export and national income has been examined for data from the period 1954 - 1971. Maximum Likelihood and least squares identification has been applied. A model of the US economy, the so called St. Louis model was used as a starting point for the examination.

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APPENDIX A, LIST OF PERSONNEL

Professor	Karl Johan Åström
(on leave fall 73, t.f. prof. G. Olsson)	
Universitetslektor	Gustaf Olsson
(on leave fall 73, t.f. lektor T. Söderström)	
Universitetslektor	Björn Wittenmark
(on leave 1.3-30.6 1974, t.f. T. Söderström)	
T.f. universitetslektor	Torsten Söderström
Forskningsingenjör	Leif Andersson
	Gunnar Bengtsson
	Ulf Borisson
	Tommy Essebo
	Ivar Gustavsson
	Lars Jensen
	Claes Källström
	Lennart Ljung
	Sture Lindahl
	Staffan Selander
	Johan Wieslander
Forskarassistent	Krister Mårtensson
Forskningsassistent	Per Hagander
Assistent	Torkel Glad
	Hilding Elmqvist
	Jan Holst
	Bo Leden
	Lars Pernebo
	Jan Sternby

Lab. ingenjör	Rolf Braun
Tekn. biträde	Britt-Marie Carlsson
Sekreterare	Eva Schildt
	Marianne Moore
Skrivhjälp	Gudrun Christensen
Gästforskare	Bruce Beck
(Visiting scientists)	Rajni Patel
	Ton van Overbeek

APPENDIX B, PUBLISHED PAPERS

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Ljung, L.: Convergence of recursive stochastic algorithms. Preprints of the IFAC Conference on Stochastic control theory. Budapest, Sept. 1974(b).

Ljung, L. and Wittenmark, B.W.: Analysis of a class of adaptive regulators. Preprints of the IFAC Conference on Stochastic Control Theory. Budapest, Sept. 1974.

Ljung, L., Gustavsson, I. and Söderström, T.: Identification of linear, multivariable systems operating under linear feed-back control. IEEE, AC. Special Issue on Identification, Dec. 1974.

Ljung, L.: Asimptoticheskie dispersii Adgoritmov Stochastiche-skoj approksimatsii, (Asymptotic variances for stochastic approximation algorithms). Accepted for publication in Auto-matica i Telemekhanika 1974(a). (In Russian).

Ljung, L. and Mårtensson, K.: Optimal control of the sulfite cooking process. Preprints of the IFAC-IFORS symposium on optimization methods/applied aspects, Varna, Bulgarica, Oct. 1974.

Olsson, G.: Measurement and control in chemical and environmental engineering. Survey paper, presented at the International Scandinavian congress on chemical engineering, KemTek 3, Copen-hagen, Jan. 29, 1974.

Olsson, G. and Holst, J.: A comparative study of suboptimal filters for parameter estimation. Symposium on digital fil-tering, Institute of Applied Mathematics, Stockholm, April 2, 1974.

Söderström, T.: (1974a) Convergence Properties of the Gene-ralized Least Squares Identification Method. Accepted for publication in Automatica.

Söderström, T.: (1974b) On the Generalized Least Squares Method. Counterexamples to General Convergence. Accepted for publication in Automatica.

Söderström, T.: Convergence of Identification Methods Based on the Instrumental Variable Approach. Accepted for publication in Automatica.

Söderström, T., Gustavsson, I. and Ljung, L.: Identifiability conditions for linear systems operating in closed loop. Accepted for publication in Int. J. Control.

Söderström, T. and Stewart, G.W.: On the numerical properties of an iterative method for computing the Moore-Penrose Generalized Inverse. SIAM J. Numerical Analysis, 11, 1, 61-74.

Wieslander, J., Pøhner, F. and Lurås, H.: Comparison of two Interactive Programs for Analysis and Design of Dynamical Systems, IFAC Symp. on Multivariable Systems, Manchester, Sept. 1974.

Wittenmark, B.: Adaptive control of a papermachine, Computers, Electronics and Control 1974, Calgary, May, 1974.

Young, P.C. and Beck, M.B.: The modelling and control of water quality in a river system", Automatica, Vol. 10, No. 5, 1974.

APPENDIX C, TECHNICAL REPORTS

7324 Olsson, G. and Holst, J.: A comparative study of suboptimal filters for parameter estimation, Nov. 1973.

7325 Jensen, L.: Dynamiska modeller för ett rum. Del 1.

7326 Jensen, L.: Dimensionering av flytande ventilstyrning.

7327 Eklund, K. and Gustavsson, I.: Identification of drum boiler dynamics, June 1973.

7328 Söderström, T.: Test of common factors of identified models. Application to the generalized least squares method. October 1973.

7329 Åström, K.J. and Olsson, G.: Process control 1972-1973, Sept. 1973.

7330 Hagander, P.: A new proof and an adjoint filter interpretation for linear discrete time smoothing. September 1973.

7331 Gustavsson, I., Selander, S. and Wieslander J.: IDPAC User´s Guide. October 1973.

7332 Hagander, P.: Kalman Filters for Processes with Unknown Initialvalues. September 1973.

7333 Jensen, L.: Veckoprognoser av fjärrvärmeeffekt.

7334 Jensen, L.: Sammanställning av mätningar och databehandling av tappvarmvattenförbrukning i Nydala i Malmö.

7335 Hagander, P.: The use of operator factorization for linear control and estimation. September 1973.

7336 Hagander, P.: Operator Factorization and other aspects of the analysis of linear systems. September 1973.

7337 Borisson, U. and Wittenmark, B.: Moisture content control on a paper machine - An application of a self tuning regulator. November 1973.

7338 Alsholm, O., Borisson, U., Stavnes, O. and Wittenmark, B.:A Feasibility study of self-tuning regulators. October 1973.

7339 Jensen, L.:Ett Coupler/Controller system. 1973.

7340 Wittenmark, B.: Master theses in automatic control 72/73. (Examensarbeten 72/73).

7341 Bengtsson, G.: A theory for control of Linear multivariable systems. November 1973.

7342 Olsson, G., Dahlqvist, K. and Ulmgren, L.: Control problems in wastewater treatment plants. September 1973. The Axel Johnson Institute.

7343 Banyasz, C.: Identification in the presence of drift. December 1973.

7344 Casti, J. and Ljung, L.: Some new analytic and computional results for operator riccati equations. December 1973.

7345 Jensen, L.: Dynamiska modeller för ett rum. Del 2. December 1973.

7346 Jensen, L.: Dynamiska konstruktionsdatamodeller och maximum likelihoodmodeller för en luftkanal. December 1973.

7347 Jensen, L.: Statiska modeller för uppvärmning. December 1973.

7401 Gustavsson, I., Ljung, L. and Söderström, T.: Identification of linear, multivariable process dynamics using closed loop experiments. January 1974.

7402 Gustavsson, I.: Identification of industrial process dynamics. January 1974.

7403 Ljung, L.: Convergence of recursive stochastic algorithms. February 1974.

7404 Ljung, L. and Wittenmark, B.: Asymptotic properties of self-tuning regulators. February 1974.

7405 Ljung, L.: On consistency for prediction error identification methods. March 1974.

7406 Ljung, L.: Stochastic convergence of algorithms for identification and adaptive control. March 1974.

7407 Olsson, G.: Measurement and control in chemical and environmental engineering. April 1974.

7408 Ekström, L,, Hänsel, R., Jensen, L.H. and Ljung, L.: Different dynamic models in an airconditioned building. July 1974.

7409 Ekström, L., Hänsel, R., Jensen, L.H. and Ljung, L.: Experiments with computer control of an air conditioning plant. July 1974.

7410 Bengtsson, G.: Lecture notes on a geometric theory for linear dynamical systems. August 1974.

7411 Söderström, T. and Stewart, G.W.: On the numerical properties of an iterative method for computing the Moore-Penrose generalized inverse. September 1974.

7412 Jensen, L.: Dynamic models for heated airtemperature to roomair-temperature. September 1974.

7413 Jensen, L.H.: A comparison between computed and measured behavior of on-offcontrol. September 1974.

7414 Jensen, L.H.: Dynamic properties of recirculation. September 1974.

7415 Jensen, L.: Dynamic Models for electrical heating devices in climate control. September 1974.

7416 Jensen, L.H.: Experiments with onoff control of room air temperature. October 1974.

7417 Jensen, L.H. and Hänsel, R.: Computer control of an enthalpy exchanger. October 1974.

7418 Ljung, L., Mårtensson, K., Hagberg, B. and Schöön, N.H.: Kinetic aspects of the acid sulfite cooking process. October 1974.

7419 Fjeld, M., Asbjörnsen, O.A. and Åström, K.J.: Reaction invariants and their importance in the analysis of eigenvectors, state observability and controllability of the continuous stirred tank reactor. October 1974.

7426 Wittenmark, B.: Master theses in automatic control 73/74. (Examensarbeten 73/74). November 1974.

APPENDIX D, INTERNAL TECHNICAL REPORTS

7324 C Borisson, U.: Rapport från "Industrial Data Processing Session", 19 juni-6 juli 1973 i Frankrike. July 1973.

7325 C Elmqvist, H.: Simnon, User´s Guide. September 1973.

7326 C Lindahl, S.: Sammanträffande med representanter för kraftindustrin med anledning av projektet "Koordinerad spännings- och turbinregulator" 1973.09.05. September 1973.

7327 C Söderström, T.: On the asymptotic estimates of least squares identification. November 1973.

7328 C Söderström, T.: On the euclidean algorithm applied to polynomials of models obtained by least squares identification. November 1973.

7329 C Wittenmark, B.: Research and education 1973. November 1973.

7330 C Gustavsson, I.: Besök i England den 17-28 September 1973. November 1973.

7331 C Van Overbeek, T.: State estimation in power networks I. A literature survey. November 1973.

7332 C Söderström, T.: Convergence properties of the generalized least squares identification method. November 1973.

7333 C Wittenmark, B.: Från författarvåndor till promovering. November 1973.

7334 C Leden, B., Hamza, M.H. and Sheirah, M.A.: Different methods for estimation of thermal diffusivity of a heat diffusion process. December 1973.

7335 C Axelsson, B., Bramsmark, G., Bredenfeldt, L., Casenberg, K., Edberg, K., Jeppson, H., Nilsson, H.G., Nordh, B. and Sandberg, E.: Systemteknik, Prognosmetoder. Projektarbete Vt-73. December 1973.

7336 C Lindahl, S. and Ljung, L.: Estimation of power generator dynamics from normal operating data. December 1973.

7337 C Åström, K.J.: Visit to control laboratories in France. December 1973.

7401 C Åström, K.J.: Ventiler och Pumpar. January 1974.

7402 C Beck, B.: Water Quality Maintenance and Control Theory. February 1974.

7403 C van Overbeek, T.: State estimation in power networks II. Comparison of methods. March 1974.

7404 C van Overbeek, T.: State estimation in power networks III. Program description. March 1974.

7405 C Åström, K.J. and Söderström, T.: Uniqueness of the Maximum Likelihood estimates of the parameters of an arma model. March 1974.

7406 C Borisson, U.: Visit to Zürich. March 18-22, 1974. April 1974.

7407 C Källström, C.: The Sea Scout experiments, October 1973. April 1974.

7408 C Andersson, B., Andersson, G., Axelsson, B., Bergkvist, E., Bohman, T., Bäckström, P., Cronholm, L.Å., Dufva, L., Engman, H., Gupta, B.N., Jörnsson, A., Persson, H., Persson, L., Olsson, O. and Ottosson, H.: Ångpannereglering. April 1974.

7409 C Åström, K.J.: A test example for adaptive control. April 1974.

7410 C Olsson, G.: Instrumentation and control for wastewater treatment systems. Reseberättelse från konferens i London och Paris 17-21 sept. 1973. May 1974.

7411 C Åström, K.J.: A self-tuning regulator for nonminimum phase systems. June 1974.

7412 C Ljung, L. and Casti, J.: Reduction of the operator riccati equation. August 1974.

7413 C Mårtensson, K. and Ljung, L.: Optimal Control of a sulfite cooking process. August 1974.

7414 C Ljung, L. and Wittenmark, B.: Analysis of a class of adaptive regulators. August 1974.

7415 C Ljung, L.: Convergence of recursive stochastic algorithms. August 1974.

7416 C Aspernäs, B., Bengtsson, B.C.T, Egardt, B., Johansson, T. and Nilsson, R.: Nivåreglering av ett tanksystem. August 1974.

7417 C Åström, K.J.: Theory and applications of self-tuning regulators. August 1974.

7418 C Åström, K.J. and Wittenmark, B.: Analysis of a self-tuning regulator for nonminimum phase systems. August 1974.

7419 C Åström, K.J.: A self-tuning parameter estimator. August 1974.

7420 C Borisson, U. and Syding, R.: Self-tuning control of an ore crusher. August 1974.

7421 C Andersson, G., Arvinius, R., Aspernäs, B., Bodelius, L., Feltberg, K.G., Foisack, P., Landberg, K., Lavemark, O., Persson, B. and Paulsson, R.: Dead beat styrning av en värme-diffusionsprocess. July 1974.

APPENDIX E, MS THESES

RE-132 Nerman H. and Perby M-L.: Simulering av andning (Respiratory simulation). September 1973.

RE-133 Jönsson G.: Parameteruppskattning i olinjär modell för ångkraftverk (Parameter estimation in a nonlinear model of a boiler-turbin unit). September 1973.

RE-134 Gunnarsson J.: Undersökning av simuleringsspråket SIMSCRIPT (An investigation of the simulation language SIMSCRIPT). October 1973.

RE-135 Hedenström J.: En enkel monetaristisk modell av Sveriges ekonomi (A simple monetarist model of the Swedish economy). December 1973.

RE-136 Gutman P-O. and Olsson R.: Dynamiska modeller för reningsverk (Dynamic models for waste water treatment plants). March 1974.

RE-137 Hylander B.: Utbildning och arbetsmarknad - En dynamisk systemmodell (Education and labor market - - A dynamic model). April 1974.

RE-138 Nilsson G.: Inloppslådereglering (Head-box control). March 1974.

RE-139 Casenberg K. and Sandberg E.: Prognosmetoder (Prediction methods). April 1974.

RE-140 Johannesson H. and Wesström J-O.: Jämförelse mellan några rekursiva identifieringsmetoder (A comparison of different recursive identification methods). August 1974.

RE-141 Bengtsson B. and Egardt B.: Ett interaktivt programpaket för simulering av självinställande regulatorer (An interactive program package for simulation of self-tuning regulators). August 1974.

RE-142 Elvgren F. and Krantz L.: Identifiering av återkopplade system (Identification of feedback systems). August 1974.

RE-143 Persson L.: Konjugerade gradientmetoden för optimala styrproblem (Investigation of the conjugate gradient method for optimal control). July 1974.

RE-144 Persson R.: Straff-funktionsmetoder för numerisk lösning av optimala styrproblem (Penalty function methods for numerical solution of optimal control problems). July 1974.

RE-145 Bengtsson L. and Paulsson S-A.: Dimensionering av operatörspanel (Construction of a operator console). August 1974.

APPENDIX F, COURSES AND SEMINARS

The courses and seminars given are summarized in this appendix.

Courses

The following courses have been given by invited lecturers, in cooperation with other departments at the University or by the personnel within the Department.

A Survey of Queueing Theory (Professor D. Wishart, University of Birmingham, England).

Filtering Theory (G. Olsson, Department of Automatic Control).

System Identification (K.J. Åström, Department of Automatic Control).

Linear Systems and Invariants (Professor P. Falb, Brown University, Providence, R.I., USA).

Geometrical Concepts in Linear Dynamical Systems (G. Bengtsson, Department of Automatic Control).

Seminars

Invited lecturers have contributed with the following seminars.

Professor H. Kushner, Brown University, Providence, R.I., USA. "Stochastic Approximation for Constrained and Unconstrained Systems", August 23, 24 and 27, 1973.

"Applications of Weak Convergence of Measures to Problems in Stochastic Control", August 28, 29 and 30, 1973.

Professor D. Tabak, Rensselaer Polytechnical Inst., USA
"Application of Modern Control and Optimization Techniques in Transportation", September 10, 1973.

Dr N. Hagander, CDC, Stockholm
"SIMULA - ett Modernt Simuleringsspråk" (SIMULA - a Modern Simulation Language"), October 12, 1973.

Mr Å. Knutsson, LM Ericsson, Stockholm
"Teletrafiksystem - ett Tillämpningsområde för Reglerteknik (Telecommunication Systems - An Area for Application of Automatic Control"), October 23, 1973.

Dr P.-Å. Wedin, University of Lund, Lund
"Icke - Lineär Minsta Kvadrat på Stora System (The Non-Linear least Squares Method Applied to Large Systems). November 23, 1973.

Professor H. Blomberg, Helsinki University of Technology, Otaniemi, Finland, "Operatoralgebra för Linjära och Tidsinvarianta Differential- och Differenssystem" (Operator algebra for Linear and Timeinvariant Differential- and Difference Systems), November 27 and 29, 1973.

"Koordinering av Hierarkiskt Styrda Dynamiska System" (Coordination of Hierarcically Controlled Dynamical Systems), December 3 and 4, 1973.

Professor G. Einarsson, Lund Institute of Technology, Lund
"Tillämpning av Estimation inom Kommunikationsteorin" (Application of Estimation in Communication Theory), November 30, 1973.

Professor T. Banks, Brown University, Providence, R.I., USA
"Mathematical Models Involving Enzyme Kinetics.
1/ Enzymatically Active Membrans", January 17, 1974.

"Mathematical Models Involving Enzyme Kinetics.
2/ Enzyme Cascades", January 17, 1974.

"A Survey of Modelling Attempts with Emphasis on What Control Theorists have been Attempting", January 18, 1974.

Professor J. Casti, University of Arizona, Tucson, Arizona, USA
"Contributions to the Unification of the Theory of Optimal Linear Filtering and Radiative Transfer", January 17, 1974.

"The International Institute for Applied Systems Analysis: Structure, Objectives and Research Program", January 18, 1974.

Professor A.G.J. MacFarlane, Manchester, England
"Recent Developments in Vector Feedback Theory and Their Application", January 30 and 31, 1974.

Dr B. Beck, visiting fellow from Cambridge University, England
"Water Quality Maintenance and Control Theory", February 27, 1974.

"Parameter Estimation in Water Quality Models Using the Extended Kalman Filter", March 7, 1974.

Dr R. Patel, visiting fellow from Cambridge University, England
"Pole Assignment in Linear Systems", March 1, 1974.

"Use of Interactive Computer Grafics for the Feedback Design of Linear Systems", March 4, 1974.

Professor P. Eykhoff, Eindhoven, The Netherlands
"Potential Application of Identification in Bio-Medicin", March 6 and 7, 1974.

Dr H.A. Spang III, General Electric, Schenectady, Penn., USA
"Measurements and Improvement of Memory Allocation in a Process Computer", March 15, 1974.

Mr B. Hylander, ASSI, Piteå
"Universitetsdynamik-Reglertekniska Metoder Tillämpade på Prognos av Studenttillströmning"(Dynamics of a University - Automatic Control Methods Applied for Prediction of Student Affiliation), April 22, 1974.

Mr K. Folkesson, SAAB, Linköping
"Dämpning av Struktursvängningar i Flygplan med Styrautomat. Några Exempel (Damping of body-bendings in an aircraft)", May 10, 1974.

Mr L. Jonsson, ASEA, Västerås
Mr T.v. Overbeek, LiH, Linköping
Dr L. Pettersson, Statens Vattenfallsverk, Stockholm
"Tillståndsestimering i Kraftsystem (State Estimation in Power Systems)", May 20, 1974.

Dr F. Filip, Bukarest, Romania
"Design of Computer Configurations for Large Production Control Systems", May 21, 1974.

Professor H. Ray, State Univ. of New York at Buffalo, Buffalo USA
"Application of Optimization Theory on Industrial Processes", May 22, 1974.

Professor J. Casti, University of Arizona, USA, Tucson, Arizona
"The Generalized H-function and the Linear Regulator Problem", May 28, 1974.

APPENDIX G, LECTURES BY THE STAFF

Members of the staff of the Department have given a number of seminars and lectures outside the University. The most important ones are listed here in chronological order:

1973

June 19	U. Borisson: Modern control theory in practical application. Industrial Data processing session, organized by Agence pour la cooperation technique industrielle et economique, Paris.
July 11	C. Källström: Modern reglerteori (Modern control theory) Lecture at Kockums Mekaniska Verkstad AB, Malmö.
July 11	K.J. Åström: Stochastic Control Theory. Invited lecture at IFAC/IFIP Conference on Dynamic Modelling and Control of National Economies, Warwick, England.
Sept 9	Meeting with representatives for the power industry. S. Lindahl: Coordinated control of a thermal power plant.
Sept 17	I. Gustavsson: Process identification and statistical modelling - a survey. Invited survey lecture given at UKAC 5th Control Convention on Modelling and Simulation for Applied Control Systems, Bath, England.
Sept 18	K.J. Åström: Adaptive control. Laboratoire d´Automatique et d´Analyze des Systems (LAAS), Toulouse, France.

Oct 2	K.J. Åström: Datorstödd dimensionering av reglersystem. (Computer aided design of control systems). STU konferens om Datorer som hjälpmedel i undervisningen, Stockholm.
Oct 9	K.J. Åström: Self-tuning regulators, MIT, Cambridge Mass., USA.
Oct 11	K.J. Åström: Adaptive control. Brown University, Providence, R.I., USA.
Oct 12	K.J. Åström: Uniqueness of ML identification of an ARMA process. Harvard University, Cambridge, Mass., USA.
Oct 9 and Oct 20	G. Olsson and J. Wieslander: Process computers - an introduction (5 lectures). SUPRA, Landskrona and SUPRA, Köping.
Oct 15-26	K.J. Åström: Seminar on stochastic control theory. Graduate School of Business, Univ. of Chicago, Chicago, USA.
Oct 25	T. Söderström: Recursive algorithms for process identification. (Rekursiva algoritmer för processidentifiering). Division of Automatic Control, Royal Institute of Technology, Stockholm.
Oct 30	K.J. Åström: System identification I. Stanford University Stanford, Calif., USA.
Oct 31	K.J. Åström: Self-tuning regulators. Stanford University.

Nov 2 K.J. Åström: System identification II. Stanford University.

Nov 7 K.J. Åström: Self-tuning regulators. UCLA, Los Angeles, Calif., USA.

Dec 12 C. Källström: Experiment med adaptiv styrning av tankbåt. (Experiments on adaptive control of a turbine tanker). Kockums Mekaniska Verkstad AB, Malmö.

1974

Jan 29 G. Olsson: Measurement and control in chemical and environmental engineering. Survey paper, International Scandinavian congress on chemical engineering, KemTek 3, Copenhagen, Denmark.

Feb 8 G. Olsson: Reglerproblem inom reningstekniken (controlling a wastewater treatment plant). Seminar at Chemical Engineering Dep., Lund University.

Feb 14 Self-tuning regulators. An information symposium at the Department of Automatic control, Lund Institute of Technology.
Contributions:
Adaptiva regulatorer (Adaptive regulators), K.J. Åström.
Självinställande regulatorer (Self-tuning regulators), B. Wittenmark.
Praktiska erfarenheter (Practical experiences).
Control of an ore crusher in Kiruna, Rolf Syding, LKAB, Kiruna.

Feb 14	Control of a paper machine, Olle Alsholm, Gruvöns bruk, Billerud AB, Gruvön and Ulf Borisson, Lund.
Feb	J. Wieslander: Simuleringens roll i reglertekniken (The role of simulation in automatic control). SIGSIM, SSI (Svenska samfundet för informationsbehandling), Stockholm.
March 20	K.J. Åström: Digital Control Algorithms Round Table Discussion, IFAC/IFIP 4th Conference on digital computer applications to process control, Zürich, Switzerland.
March 21	U. Borisson: An industrial Application of a self-tuning regulator, IFAC/IFIP 4th Conference on digital computer applications to process control, Zürich, Switzerland.
March 22	K.J. Åström: Paper Machine Dynamics. 4th IFAC/IFIP conference on digital computer applications to process control, Zürich, Switzerland.
March	J. Wieslander: Interaktiva program (Interactive programs). Datorcentrum, KTH(Centre of computing) Royal Institute ofTechnology, Stockholm.
April 2	G. Olsson: A comparative study of suboptimal filters for parameter estimation. Symposium on digital filtering, Institute of Applied Mathematics, Stockholm.
April 2	J. Holst: Adaptive Prediction. Symposium on Digital Filtering, Stockholm.
April 5	K.J. Åström: An Intoduction to self-tuning regulators, Imperial College, London.

April 17	K.J. Åström: Theory and Application of Self-tuning Regulators, Cambridge University, England.
April 23	P. Hagander: Nonlinear, bilinear and linear compartment models. UCLA, Los Angeles, USA.
April 24	G. Olsson: Control problems in wastewater treatment. Symposium arranged by Swedish Board for Technical Development (STU), Stockholm.
May 8	G. Olsson: Några nya trender inom reglertekniken med tillämpning inom processindustrin (Some new developments in control theory applicable to the process industry) STFI, Stockholm.
May 9	G. Olsson: Adaptive filters. Division of Telecommunication Theory, Lund Inst. of Technology, Lund
May 13-17	Automatic control - current theory. Course for industrial people given in Lund. Contributions: 1. Introduction. K.J. Åström. 2. Analys och syntes i tidsplanet (Analysis and synthesis in the time domain). 6 lectures by G. Bengtsson and J. Wieslander. 3. Datorer som regulatorer (Computers as controllers) 3 lectures given by U. Borisson. 4. Analys och syntes med hänsyn till störningar (Analysis and synthesis of stochastic systems) 4 lectures by L. Ljung and G. Olsson. 5. Processidentifiering (Process identification) 3 lectures by I. Gustavsson. 6. Användning av optimeringsteori för syntes av reglersystem (Synthesis of control systems by optimization theory) 4 lectures by K. Mårtensson, S. Lindahl and G. Olsson.

May 13-17	7. Självinställande och adaptiva regulatorer (Self-tuning and adaptive controllers) 2 lectures by U. Borisson. 8. Summary of the course. 1 lecture by G. Olsson.
May 14	B. Wittenmark: Industrial applications of a self-tuning regulator. Univ. of Calgary, Calgary, Canada.
May 16	I. Gustavsson: Systemidentifiering (System identification). Division of Telecommunication Theory, Lund Institute of Technology, Lund.
May 25	B. Wittenmark: Adaptive control of a paper machine. Symposium on computers, electronics and control, Calgary, Canada.
May 29-30	Process identification seminars. Course for industrial and university people given in Lund. Contributions: 1. Processidintifiering - en översikt av metoder (Process identification - a survey of methods), K.J. Åström. 2. Praktiska synpunkter på processidentifiering (Practical aspects on process identification), I. Gustavsson. 3. Interaktiva identifieringsprogram (Interactive programs for identification), J. Wieslander. 4. Identifiering av återkopplade system (Identification of closed loop systems), L. Ljung. 5. Rekursiva metoder (Recursive methods), T. Söderström. 6. Identifiering av båtdynamik (Identification of ship dynamics), C. Källström.

May 29-30 7. Utvärdering av ytvikts- och fukthaltsreglering av pappersmaskin med användning av identifiering (Evaluation of basis weight and moisture control of a paper machine using identification techniques), B. Häggman.

8. Identifiering av kärnreaktordynamik (Identification of nuclear reactor dynamics), G. Olsson.

9. Identifiering av dompanna - en olinjär modell (Identification of a drum boiler - a nonlinear model), S. Lindahl.

10. Identifiering av klimatanläggningar (Identification of interior climate), L. Jensen.

11. Bestämning av konstanter för värmediffusion med hjälp av identifiering. (Determination of heat diffusion coefficients by identification), B. Leden.

12. Prognosticering av ekonomiska tidsserier (Prediction of economical time series), J. Holst.

May 30 P. Hagander: Computer simulation of cancer cell kinetics. UCLA, Los Angeles, Calif., USA.

June 11 K.J. Åström: Adaptive control - an overview. Imperial College, London, England.

June 13 K.J. Åström: System identification - implications for application of modern control theory. Cranfield college of Aeronautics, England.

June 14 B. Wittenmark: Industrial applications of a self-tuning regulator. Univ. of Alberta, Edmonton, Alberta, Canada.

June 19 L. Ljung: Reduction of the operator Riccati equation. IRIA, Symposium on Stochastic Control Theory, Paris.

June 19	K.J. Åström: Theory and Applications of Self-tuning Regulators. IRIA Symposium on Stochastic Control Theory, Paris.
June 25	K.J. Åström: Self-Tuning Regulators Part 1. Imperial College, London.
June 26	K.J. Åström: Self-Tuning Regulators Part 2. Imperial College, London.

APPENDIX H, TRAVELS

K.J. Åström was on sabbatical leave for a total of 6 months. He participated in the IFAC/IFORS International Conference on Dynamic Modelling and Control of National Economics in July-73. In September he visited Control laboratories in France (Trip report 7337C). In September and October he visited Universities in USA including MIT, Harvard, Brown, Graduate School of Business, University of Chicago, Stanford, University of California, Berkeley, and University of California, Los Angeles and the industries Measurex, Santa Clara and Systems Control. In March Åström participated in the IFAC/IFIP 4th International Conference on Digital computer applications to process control. During April and June Åström was visiting professor at Imperial College in London. In June he participated in the IRIA symposium on Stochastic Control Theory in Paris.

Ulf Borisson visited an "Industrial Data Processing Session" in France during June-July 1973. The session was sponsored by the French government and arranged by an organization ACTIM (Agence pour la cooperation technique industrielle et économique). The visit is described in Borisson (7324 C). Borisson also participated together with K.J. Åström in the IFAC conference on Digital Computer Applications to Process Control in Zürich, March 1974, which is reported in Borisson (7406 C).

In September 1973, I. Gustavsson visited a number of universities, in particular Departments of automatic control, in England. He also gave an invited survey lecture on process identification at the UKAC 5th Control Convention on Modelling and Simulation for Applied Control Systems. The experiences from this conference and the visits are given in Gustavsson (report 7330 C).

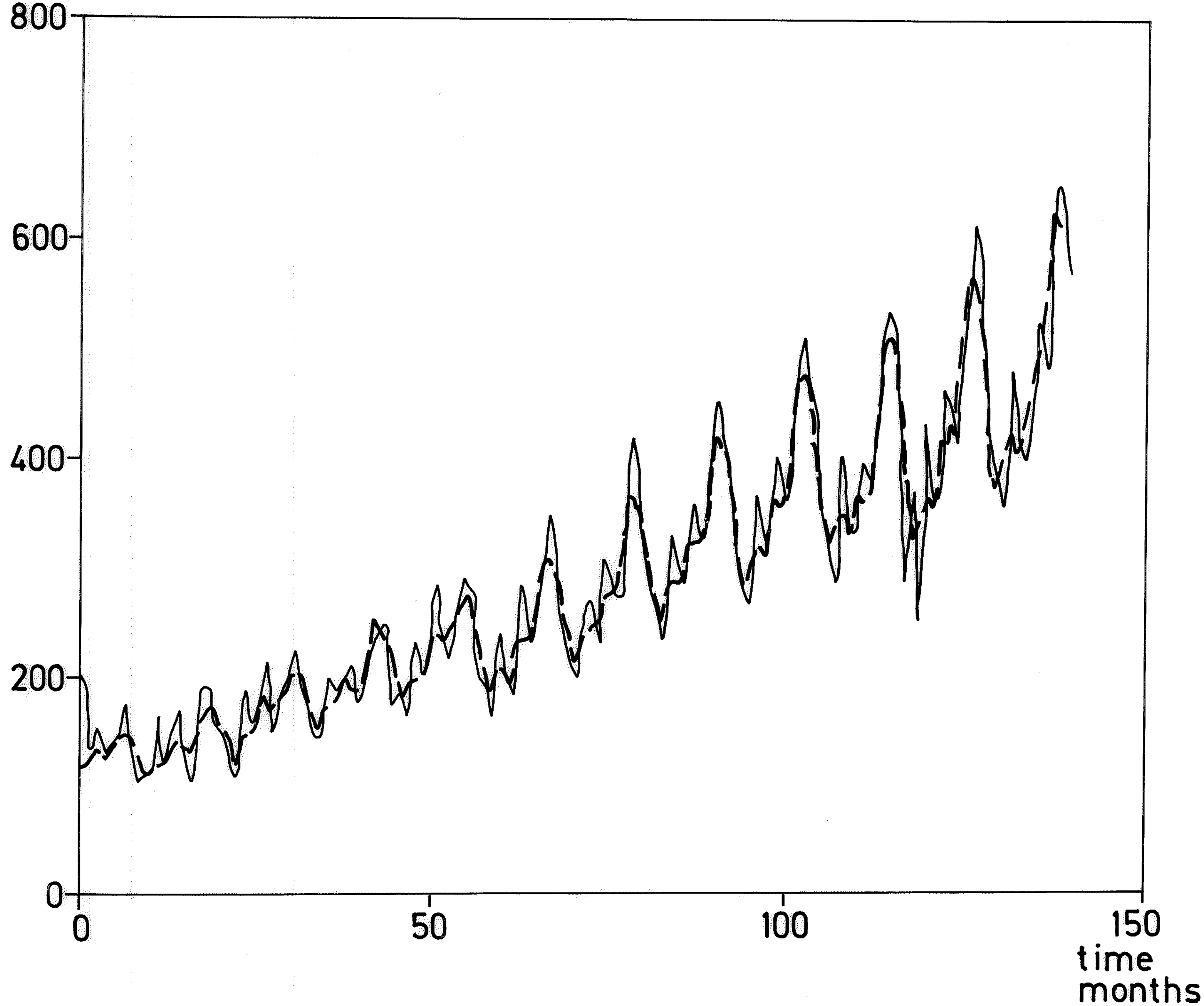
Per Hagander visited Tucson, Arizona during February 1974 and UCLA, Los Angeles, USA from March until the end of August 1974. The visit is documented in a forthcoming report.

Claes Källström participated in the IFAC/IFIP symposium on Ship Operation Automation in Oslo, Norway, July 2-5, 1973.

Lennart Ljung participated together with K.J. Åström in the IRIA Symposium in Paris, June 1974.

Gustaf Olsson attended a workshop on "Automation of Waste-water treatment plants" arranged by the International Association of Water Pollution Research in London during September 1974. The symposium also included a visit to the main waste-water treatment plant in Paris. The travel is documented in Olsson (7410 C).

Björn Wittenmark visited University of Calgary, Canada and the Brown University, Providence, R.I., USA during the period February 27 - August 28 1974. The visit is reported in Wittenmark (report 7429 C).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