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ACTIVITY REPORT
1974-1975

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LTH

Department of Automatic Control   Lund Institute of Technology

ACTIVITY REPORT 1974-1975

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ABSTRACT

This report gives a survey of the activity at the Department of Automatic Control during the academic year 1974-1975. Five different courses were given at the civ ing level (≈ MS). About 480 students participated in the courses. During the year 21 MS-theses and one PhD thesis were completed. The research centered around the areas system identification, adaptive control, computer aided design of control systems. The applications covered modelling and autopilots for supertankers, modelling of activated sludge processes, and control of climatized buildings. The members of the staff wrote 39 papers and 50 technical reports.

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1. INTRODUCTION

This report is intended to give an overview of the research and education at the Department of Automatic Control at Lund Institute of Technology. The report is intended to serve as a tool for communication with universities, institutes, research groups and industries. The report has been appearing yearly. This report has the same format as that of the previous year.

The main lines of research are stochastic control theory, including system identification and adaptive control, system theory and process control applications. During this year the proportion of applied work has been unusually high with projects in coordinated control of thermal power stations, modelling and adaptive control of supertankers, control of waste-water treatment plants and control of climatized buildings. This reflects partly the interest of students and coworkers and partly the increased interest from industry to apply modern control theory.

During the period covered by the report substantial discussions concerning the direction of the research and education have been carried out. This discussion will result in a new research program in the coming years. Although the discussions are not complete the current opinion is that the effort in system identification will decrease, that the activity on self-tuning regulators will increase considerably, and that the activity in system theory will be increasingly directed towards large and hierarchical systems. Our contacts with industry clearly indicates that mini- and microcomputers will find increasing use in control systems. This has been reflected in changes in the course on hardware and software for automatic control. To boost our knowledge both on hardware and software several small MS projects have been initiated in this area. It is not yet clear if this will result in a more substantial effort.

It is clear that the techniques developed for interactive design of control systems are tremendously powerful. It would be highly desirable to incorporate these methods in the regular courses. This has been initiated in the sense that revision of the courses has been started. The implementation will, however, require a reasonable investment in computer terminals which is not yet within reach.

In view of the discussions related to energy research which have been inspired by the energy crises we would also like to give a few comments relating to this area of application. It is clear that there are potentials to save energy by improved control in many cases. Perhaps more important is that the research in Automatic Control provides a good framework to discuss many of the systems problem associated with energy systems and energy savings. Tools like modelling, simulation and optimization are very useful in this context. Among specific projects that are directly related to energy we can mention adaptive prediction of power consumption (4.3), online optimization of oil burners (5.1), coordinated control of thermal power stations (8.1) and control of climatized buildings (8.4).

The research has been supported by the Swedish Board for Technical Development (STU), the National Swedish Board of Building Research (BFR), the Swedish Natural Science Research Council (NFR) and the Institute of Applied Mathematics (ITM). This support is gratefully acknowledged.

We have also benefitted very much from our partners in joint projects, the Swedish State Shipbuilding Experimental Tank (SSPA), Kockums Mekaniska Verkstads AB, Datema AB, and the Käppala Wastewater Treatment Plant.

2. EDUCATION

During the year, courses are given for the civ ing degree as well as for the PhD degree. During the summer 1974 a special course sponsored by the "Nordiska forskarkurser" (Nordic Research Education) was arranged as a Scandinavian summer school on the topic Theory of dynamical systems.

2.1 Civ ing program

Five undergraduate courses have been given during the year, a basic course (allmän kurs), a basic course for chemical engineers (mindre kurs), an advanced course (fortsättningskurs), a system techniques course (reglerteknik-systemteknik) and a course on computers in control systems (datorer i reglersystem).

The courses have been presented in last annual activity report.

During the year some minor revisions have been made. New laboratory exercises have been developed in stochastic systems in the advanced course. New versions of the lecture notes in system techniques and in computers in control systems have been developed.

2.2 Master thesis

The thesis work (examensarbete) is an integrated part of the civ ing program. 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 21 theses have been finished by 30 students. Abstracts of the theses are presented in a separate report, see Wittenmark (7519). A list of the reports is given in appendix E. All theses are written in Swedish with an English abstract.

2.3 PhD program

The graduate program is a four year curriculum leading up to the PhD degree and is based on the "civilingenjör" degree. The graduate studies are dominated by course work during the first three or four semesters. Some of the courses are given as formal lectures, see appendix F. Others are defined by books, lecture notes and are presented in study groups or taken by single students.

During the academic year there have been 13 active PhD students. One PhD thesis has been completed namely

Bo Leden: Identification and Dead-Beat Control of
a Heat Diffusion Process. (7508)
May 26, 1975

2.4 Control laboratory

The computer PDP 15 has been used about 5.500 hours during the year. New equipment has been added to the computer system during the year. A 1.2 M word disk memory with a PDP-11 central processing unit was added to the system. Thereby the system capacity has been increased considerably, expecially for the interactive program activities. The computer has been used both for interactive computation, remote control and real time calculations.

An operators panel for a micro computer system Intel 8008 has also been designed and built. By the panel it is possible to add and change programs by thumb wheels. Registers and memory cells can also be displayed. A z--transform regulator was implemented using a PDP 15 crossassembler and a linking loader.

2.5 Continuing education

As the external contacts are considered important for the research and education, courses and contact meetings have been arranged during the year.

A two-day course on Interactive computation of dynamical systems was held in Lund on May 22-23, 1975. The course was arranged in collaboration with the Liasion Office for Industrial Contacts (Kontaktsekretariatet) at the Lund University. About 55 people from industry and other research centres participated. The course program is given in appendix G. Three program systems were presented and demonstrated during the courses, the program IDPAC for interactive data analysis and identification, the program system SYNPAC for interactive synthesis of systems with linear quadratic control and the program system SIMNON for simulation of non-linear systems.

During the year a course in control theory has been given by some staff members at the Kockums Mekaniska Verkstad AB, Malmö. A survey course on 15 hours was given during the Fall 74 for about 50 engineers, starting with the Managers. During the spring a 45-hour course on linear system control has been given for about 30 engineers.

2.6 Scandinavian Summer School

In 1974 the Department was given a financial support from the Nordic Research Education (Nordiska forskarkurser) to arrange a summer school on the topic Theory of Dynamical Systems. The course was given at the Department from July 22 to August 2, 1974.

In the course the basic theory of dynamical systems was treated. Algebraic system theory and the consequences of it were emphasized. Four invited guest lecturers contributed to the course program:

Professor R E Kalman, University of Florida, Gainesville, USA

Professor M Wonham, University of Toronto, Toronto, Canada

Professor H Blomberg, Helsinki University of Technology, Otaniemi, Finland

Professor H H Rosenbrock, University of Manchester, England

The professors Kalman, Wonham and Blomberg lectured on algebraic system theory from different aspects. Professor Rosenbrock gave a sequence of lectures on his theory of multivariable systems.

The participants were both graduate students and professional researchers from universities and research institutions. There were a total of 59 participants from four Nordic countries; 10 from Finland, 4 from Norway, 5 from Denmark and 40 from Sweden.

3. SYSTEM IDENTIFICATION

The research on system identification has been concentrated on the areas:

- accuracy of identification and its relation to the design of experimental conditions
- convergence and accuracy of recursive identification algorithms
- identifiability problems
- estimation of optimum structures for multivariable systems
- consistency of prediction error identification methods

The program facilities have been further developed and used in several applications, see section 6. The interactive program IDPAC was presented on an information course about interactive programs for people from industry, see section 2.5. One PhD thesis has been completed, Leden (7508), in which identification of a thermal diffusion process was one of the major parts.

3.1 Accuracy of identification and its relation to the design of experiments

The estimates obtained from data from an identification experiment depend on a number of items, such as

the model structure, $\mathcal{M}$
the identification method, $\mathcal{J}$
the experimental conditions, $\mathcal{X}$.

The effect of these items on the asymptotic accuracy has been studied.

The set of models, $\mathcal{M}$, should be chosen as small as possible. In some cases it is also required that it includes a "true" description of the system.

Inclusion of additional parameters decreases the accuracy.

The influence of J has been studied for two different approaches to identify systems operating in closed loop. A direct application of the maximum likelihood method neglecting the feedback will always be the best possibility, although there can be other techniques giving the same accuracy.

The effect of different experimental configurations, X, on the identifiability and the accuracy of the estimates has been investigated. Special attention has been paid to systems operating in closed loop and to the effects of the feedback on the accuracy. The results show that identification of systems operating in closed loop is theoretically possible and that it can give acceptable accuracy. In fact, it is shown for the case of constrained output variance that closed loop experiments can give better accuracy than open loop experiments.

The results have been presented in Söderström-Ljung-Gustavsson (7428) and in Söderström-Ljung-Gustavsson (1975).

3.2 Recursive identification methods

A number of recursive identification methods has been examined, namely

- the recursive least squares method
- the recursive generalized least squares method
- the instrumental variable method
- the extended least squares method
- the approximate recursive maximum likelihood method.

All these methods can in fact be described by very similar algorithms.

The algorithms are nonlinear and stochastic difference equations which make a direct analysis of convergence extremely difficult. However, it has been shown that a theoretical examination is possible by studying the stationary solutions of a certain system of nonlinear ordinary differential equations. Then it is not too difficult to get the possible limit points as well as to examine their stability properties. In the following it is assumed that the model structure is of proper form for the system considered.

For the recursive least squares method and the instrumental variable method the parameter estimates will always converge to the true values. For the recursive generalized least squares method the estimates will converge to the true values if the signal-to-noise ratio is large enough. On the other hand, if this ratio is small, it is possible that the estimates converge to false values.

The extended least squares method has been used extensively in many applications all around the world. It seemed to be a reasonably good algorithm even if a strict convergence proof was lacking. However, constructed counterexamples show that there are systems for which the estimates never converge, Ljung-Söderström-Gustavsson (1975). For moving average processes and for first order processes of autoregressive-moving average type this method has been proved to converge to the true values.

For the approximate recursive maximum likelihood method the estimates will always converge to the true values if the corresponding off-line maximum likelihood method does so. This is true for autoregressive-moving average processes and for systems with an input signal if the system has a very small or a very large signal-to-noise ratio.

The results have also been illustrated by extensive simulations, showing that the approximate recursive maximum likelihood method is advantageous also from an accuracy point of view. The comparison has been made for the case of correlated disturbances.

These results have been presented in Söderström-Ljung-Gustavsson (7427) and in Ljung-Söderström-Gustavsson (1975).

3.3 Recursive stochastic algorithms

It has been described in previous annual reports how an ordinary differential equation (ODE) can be associated with recursive stochastic algorithms. Global stability of this ODE implies convergence w. p. 1 for the algorithm, and the trajectories of the ODE are in a certain sense the expected paths of the algorithm. These results have been extended to more general schemes in Ljung (7505C), where it also is shown that only stable stationary points of the ODE are possible convergence points of the algorithm. The ODE thus contains essential information about the asymptotic behaviour of the algorithm, and is a useful tool for the analysis. The technique has been applied to analysis of recursive identification algorithms as described in section 3.2, to analysis of adaptive regulators in Åström-Borisson-Ljung-Wittenmark (1975) and to algorithms for state estimation in power systems in Ljung-Lindahl (1975).

3.4 Consistency of prediction error identification methods

The work on consistency of certain identification methods (including e. g. maximum likelihood- and min-max entropy-methods) has continued and some new results are given in Ljung (1975a). While consistency results essentially are concerned with the case when the true system can be exactly modeled within the chosen model set, it is of particular interest in practice to know what happens if the true system is more complex than the admissible models. This situation is analysed in Ljung (1975b) where some general results on the convergence of the estimates are proved.

3.5 Parameterization of multivariable systems for identification purposes

The problem of parameterizing multi-output systems is of vital importance for practical applications of identification. The problem is closely related to canonical representation of transfer functions. However, in the identification application we are less concerned with uniqueness of forms of representations and the major interest is in identifiable parameterizations (unique or not). This calls for special parameterizations for the identification problem. In a paper submitted to the 4th IFAC Symposium on Identification it is discussed how they can be selected from pre-analysis of data and Rissanen-Ljung (1975) concerns the sequential selection of parameterizations within the parameter estimation procedure. This work has been performed together with Prof Rissanen at IBM Research, San Jose, California.

3.6 Linear estimation

Lennart Ljung has spent most of the year with Prof Kailath's group at Stanford University, California. Much of the work there has concerned linear estimation problems. In particular formal analogies with scattering theory have been exploited for several new results in estimation theory.

4. ADAPTIVE CONTROL

There have been published a large amount of papers on adaptive control in the last years. In order to follow the recent development of adaptive controllers a literature survey has been done, Wittenmark (1975a). The survey covers adaptive controllers where the stochastic nature of the processes and/or the parameters of the process has been taken into account when deriving the controller.

4.1 Dual control

The work on the example described in last years' activity report has been completed and written down in Sternby (7430). For general systems good approximations must be found, since the optimal control laws can in most cases not be calculated.

Consider the system

$$A^*(q^{-1})\ y(t) = B^*(q^{-1})\ u(t-1) + e(t)$$

where the parameters in the A^* and B^* polynomials are unknown stochastic processes. The parameters in the process can be estimated using a recursive identification scheme. Based on the estimated parameters a control signal can be derived which minimizes the lossfunction

$$V_1 = E\ \{(y(t+1) - y_{ref})^2\}$$

The controller will be non-dual since it is not taken into account that the control signals must be chosen to get good control as well as good estimation. The controller is not rewarded if it makes a control action in order to get better estimates which then can be used to improve the control in future steps. To get a compromise between the control and the estimation the lossfunction can be changed to

$$V_2 = E\ \{(y(t+1) - y_{ref})^2 + \lambda\ f(P(t+k))\}\quad .$$

P(t+k) is the variance matrix of the errors of the parameter estimates. The lossfunction must now be minimized numerically. The resulting controller will be a suboptimal dual controller which in an active way tries to make good control and good estimation. The properties of the controller are investigated in Wittenmark (1975b). For some simple examples the new controller has proved to have good properties and the controller has been compared with other suboptimal controllers suggested in the literature.

Further investigations of the controller and comparisons with others on some first order systems are made in the MS thesis Abramowicz-Stymne (RE-159).

4.2 Self-tuning regulators

Self-tuning regulators has been an area of research for the Department for some years. The main ideas and results concerning self-tuning regulators are summarized in Åström, Borisson, Ljung and Wittenmark (1975). The theoretical aspects as well as the applications are covered.

A self-tuning regulator for batch processes

In many industries it is common with parallel batch processes where the raw material comes from one source. Assume that there are r processes in parallel and that they are sequenced in the order 1, 2, 3,...,r, 1, 2... , i e the processes are started one at a time and information from previous processes are available when the next one is started. The system can be described as

$$y(t) = a_i\ u(t) + b_i\ v(t) + \frac{C^*(q^{-1})}{D^*(q^{-1})}\ e(t)$$

where y(t) is the output signal from the t:th batch and u is the control signal. The signal v can be a measured variable which can be used for feedforward. The process

$$\frac{C^*(q^{-1})}{D^*(q^{-1})}\ e(t)$$

models the variation in the incoming raw material. One example of such processes are batch digesters in the paper industry. The raw material is the wood chips. The output signal is the κ-number. The control signal is the temperature and v is the amount of chemicals added to the batch.

It is now assumed that the parameters a_i, b_i $i=1,..,r$, and the parameters in the C* and D* polynimals are unknown. The parameters are estimated using the method of extended least squares. Based on the estimated parameters the control signal is chosen in order to minimize the variance of the output of the process. This self-tuning regulator for batch processes has been investigated in Jeppsson (RE-156).

Simulations show that the regulator has good properties. Already after a few samples the controller makes almost as good control as the optimal controller for known parameters. The controller has the advantage that information from one process can be used in the control of the following processes by predicting the variation in the raw material. It can also follow variations in the process and disturbance parameters.

4.3 Adaptive prediction

The research on self-tuning regulators has also resulted in methods for adaptive prediction. The problem of predicting unknown stochastic processes can be attacked by making a real time estimation of the parameters in the underlying process. In analogy with the self-tuning regulator it is also possible to estimate the parameters in the predictor directly. The basic idea and the basic properties of the self-tuning predictor is discussed in Wittenmark (1974).

The structure of the model of the process can be chosen in many ways. Apart from a model consisting of the estimates of the system parameters, different models which contain estimates of the predictor parameters could be used. One of these is discussed in Wittenmark (1974) and another one in Holst(7433C). It has been shown that all these structures of the model in the one step ahead prediction case give the same trajectories of the parameter estimates when started in equivalent initial conditions. For multistep prediction this is however no longer the case for all of the considered structures.

The self-tuning predictor has been applied to real data for prediction of the hourly load on the power network (Holst, 7433C) and for prediction of urban sewer flows (Beck, 7432C). In both cases the algorithm had to be modified in order to handle the time-varying parameters and the periodic components of the data series. The periodic component was represented either by a profile over past data or by the foregoing period in the data. The result of these prediction studies compares favourably with other prediction methods. In connection with the problem of representation of the periodic component also simultaneous prediction of the whole or a part of the period has been studied.

4.4 Self-tuning regulators for multivariable systems

To control multivariable processes, a self-tuning regulator has been studied, which is not based on the solution of a Riccati equation. This work has been done mainly by Ulf Borisson. As the control strategy is calculated in each sampling interval in self-tuning algorithms, it is favourable to have a strategy that is easy to compute. Therefore the minimum variance strategy has been used. This is a special case of the linear quadratic control strategy with no cost on the control action. The process to be controlled is described by a linear vector difference equation including coloured noise. It is assumed that there are as many inputs as outputs, that the impulse response starts with a nonsingular matrix and that the process is minimum phase.

It has been shown that the minimum variance strategy for SISO systems can be generalized to the multivariable case. The optimal strategy is then described by a linear vector difference equation. The strategy is independent of the weighting matrix of the criterion function and of the covariance matrix of the random variables describing the disturbances.

The self-tuning algorithm considers the process parameters as constant but unknown. It includes a least squares estimator and a minimum variance controller. By choosing a feasible structure of the estimator the control strategy can be obtained directly from the estimated parameters in each sampling interval. Presently the properties of the algorithm are analysed, and for some cases it can be shown that the regulator will give the optimal strategy, if the estimated parameters have converged. It can also be shown that an optimal strategy is obtained when feedforward compensation is included.

Simulated examples indicate that the minimum variance strategy is obtained in general. A simulation study of head-box control for a paper machine has also been carried out. The inputs of the head-box are stock flow and air flow and the outputs are stock level and total pressure. The results show that the multivariable self-tuning regulator works well on this process.

5. COMPUTATIONAL CONTROL

The main effort in computational control has been concentrated around constrained minimization and its applications to the synthesis of controllers. These problems are discussed in 5.1. The program library for the Univac 1108 at the Lund University Data Center is discussed in 5.2.

5.1 Constrained optimization

Numerical algorithms for the constrained optimization problem

$$\begin{aligned}&\min f(x)\\ &g_i(x) = 0 \qquad i = 1,\dots,q\\ &g_i(x) \leq 0 \qquad i = q+1,\dots,m\end{aligned}$$

have been studied. They are based on the augmented function

$$F(x,p,c) = f(x) + \frac{1}{2c}\sum_{i=1}^{q}[(cg_i(x) + p_i)^2 - p_i^2] + $$
$$+ \frac{1}{2c}\sum_{i=q+1}^{m}[(cg_i(x) + p_i)^2 - p_i^2]$$

The convergence speed of different updating methods for p have been studied. It is shown in Glad (7503) that a suitable updating formula for p combined with a Quasi--Newton method for x, gives superlinear convergence. In the report there is also a comparison of different algorithms on numerical test problems.

The work on the combination of optimization and simulation, has continued and the standard versions of SIMNON both on the PDP-15 and on UNIVAC 1108 now contain constrained optimization routines, see Glad (7424).

The multiplier methods can be extended to optimal control problems:

$$\text{minimize } J = \int_0^T L(x,u)dt + F(x(T))$$

$$\dot{x} = f(x,u)$$

$$x(0) = a$$

It is shown in Glad (7503) that the value of c which is necessary for

$$J = \int_0^T \{L(x,u) + p^T(f(x,u) - \dot{x}) + + \frac{c}{2}(f(x,u) - \dot{x})^T (f(x,u) - \dot{x})\} dt$$

to have an unconstrained minimum is determined by a certain Riccati equation.

During the spring 1975 the finite dimensional optimization algorithm has been applied to on-line optimization. The optimal adjustment of the air flow of an oil burner has been determined in collaboration with the Department of Machine Design. The criterion is to maximize the CO_2--content of the flue gases while keeping CO-content low. The value of the loss function for a given value of the independent variables is then given by direct measurements from the process and not by a mathematically defined function.

5.2 Program library at Univac 1108

During the year the time sharing facilities at the Data center have increased. A new memory bank has been added to the system, and the response times have decreased. A graphical display Tektronix 4012 has been bought at the Department. With these new facilities interactive computation has been made possible not only at the PDP 15 but also at the Univac 1108 computer.

The program package SIMNON for interactive simulation of non-linear systems has been transferred to the Univac computer. Then the possibilities have been increased considerably for external users to run the program. It has been used by several users at the Department and at other institutions, e g Kockums Mekaniska verkstad AB, Malmö. Other external users have used the PDP 15 computer for interactive programming, see section 6.

The program package LISPID for parameter estimation in linear state space models has been used for several projects. Besides ship dynamics design it has been applied for farmacokinetic studies and for water pollution models. It has been developed into a form that allows for solving very general identification problems.

It has also been used by teleprocessing by the Swedish State Shipbuilding Experimental Tank (SSPA) in Gothenburg.

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 result of the project is a set of interactive command-driven programs to solve some common practical control engineering problems. The command language may be regarded as a high-level language specially adapted to a certain class of problems. The language also includes elements to form subroutines (MACRO's), loops, condition-tests, and special I/O-dialogues.

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.

It is possible to group a sequence of commands together into what we call a MACRO. This concept is very similar to what is called subroutines or procedures in other languages.

A MACRO may contain commands to perform branching, testing, looping and I/O. This has two important consequences. One is that within a problem-complex some frequent sub-problems may be solved within a MACRO thus making the over-all problem easier and more efficient to solve and survey. The other is that MACROs which put questions to and receive answers from the user are possible and easy to implement. This gives a nice way of introducing the beginner in the use of these programs.

The command decoding and MACRO handling routines are common to all the programs that have been implemented. The programming for the entire set of programs have been done in FORTRAN with the aim of making them portable.

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

The program IDPAC for interactive datahandling and identification has been further developed and extended. The data handling routines include data moving, scaling, trend estimation etc. Parameter estimation algorithms includes Maximum Likelihood and Least-Squares estimation of multiple-input single-output systems, correlation analysis, model analysis as well as statistical tests.

During the last year a set of commands for ordinary least-squares estimation have been implemented. It has been constructed in such a way that it utilizes the possibility of the QR-method of recursively dropping parameters in the model.

The program for synthesis of multivariable linear systems, SYNPAC, has been extensively modernized during the year.

The Research Institute of National Defense (FOA) has shown considerable interest in this program and it will be implemented in Stockholm in the near future on a DEC-10 computer. Also at Atomenergi AB, Studsvik, there are advanced plans to transfer the program package to their computer system. Similarly, IDPAC is being transferred to a process computer installation at the STFI (Swedish Forest Products Research Laboratory). In the near future it will probably also be transferred to the Atomenergi AB, Studsvik.

6.3 Interactive program for simulation of nonlinear systems (SIMNON)

SIMNON is in frequent use at the Department and has also been moved to the Dec-10 system at the Stockholm Computing Center. This year SIMNON was moved to the computing-center here in Lund, thus making it available to a wider range of users.

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 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 separately define subsystems, with inputs and outputs, and then connecting them. Each subsystem could be described wither by ordinary differential equations or difference equations.

A user's guide has now appeared, see Elmqvist (7502).

6.4 Presentation

The interactive program packages have been presented to a greater public at a number of occations, e g in Wieslander et al (1974). A well attended contact meeting was also helt in Lund, May 22-23 in 1975, see also 2.5. During these days an extensive description and examplification of the programs and their use were given by a number of members of our institute, and also by people from industry, see also 2.5 and appendix G.

6.5 Program exchange

The cooperation 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 Pacage (CDP) has been received.

It was first implemented two years ago, but a new and revised version was implemented on our PDP-15 by Mrs B Shearer during her stay here two weeks in May 1975.

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.

Attempts were made to get two other packages from Imperial College running, viz, the Multivariable Design Package and the Model Reduction Package.

Some problems arose which prevented a complete success, but we will get revised versions from them and have a new go at it.

Likewise, a transfer of IDPAC and SIMNON to Imperial College is planned.

7. SYSTEM THEORY

7.1 Multivariable systems

A basic problem in multivariable control theory is to assign the external dynamical behaviour of the system. The specific purpose could be noninteraction, model matching or disturbance localization. These problems can algebraically be formulated as solving linear matrix equations over the field of rational functions in s, with some additional requirements to ensure the existence of desirable implementations. A specific version of this problem, model matching and disturbance localization, is solved in Bengtsson (1975a) with the additional restriction that the control must be causal. The noncausal and the generic case are treated in Bengtsson (1975b). In the generic case, the system is regarded as a datapoint (p) in a normed linear vector space (R^N). Conditions are given which ensure solvability for "almost all" cases, i.e. for all systems (p) except those on a proper algebraic variety in R^N.

These results are presently being generalized to give a more or less unified treatment of a whole range of problems which are essential in linear control theory. A very preliminar version of this generalization is ,described in Bengtsson (1975c).

As a part of the project interactive design, a set of computer programs has been developed for synthesis of multivariable system. In Bengtsson (7501) it is shown that abstract linear algebra used in the geometric state space theory can be transformed to economic computational algorithms provided a linear subspace is described by a basis of a certain type, denoted unity form.

7.2 Dead-beat control

The work on identification and dead-beat control of a diffusion process has resulted in a PhD theses, Leden 7508.

The major part of the work on modelling and identification has been reported earlier (Reports 7009, 7010, 7121 and 7334). New results on lumped state space models of the diffusion process are given. These models are derived using finite difference techniques. It is found that the accuracy of these models is essentially determined by the number of intervals used and that a refinement of the approximation to the partial derivatives only improves the accuracy to a certain extent. Moreover, it is important to use smaller intervals near the ends of the rod where the temperature gradients may be larger.

The nature of the heat equation implies that it takes considerable time for a solid to reach a steady state temperature profile. The purpose of many temperature control systems is therefore to speed up the time required to reach equilibrium. This means that it is quite reasonable to consider dead-beat control strategies.

A dead-beat control theory for sampled-data control of a linear time-invariant multivariable system has been developed. The following types of controllers are proposed.

state dead-beat controllers
output dead-beat controllers
constrained output dead-beat controllers
minimum gain dead-beat controllers

The dead-beat controllers drive the state or the output of a discrete-time system to zero in a minimum number of time steps, using linear feedback from the state variables of the system. The system controlled by an output dead-beat controller may be unstable. Therefore, it is important to derive output dead-beat controllers which give a stable closed loop system. These controllers are the constrained output dead-beat controllers. Numerical aspects of the algorithms for computing the dead-beat controllers are presented. Experimental results show that the dead-beat strategies are very relevant for controlling the diffusion process (see further section 8.5).

7.3 Sampled data systems

The relation between the sampling period and the location of the zeroes of a sampled system has been investigated by I Gustavsson and P Hagander. Most minimum phase systems seem to produce zeroes inside the unit circle, but a small direct term or a time delay that is a fraction of the sampling period might give zeroes outside. This happens for example with fast sampling of systems whose high frequency phase lag is more than π radians.

8. APPLICATIONS

8.1 Power systems (S Lindahl)

The modelling work previously described has been polished and is now beeing written up. A regulator for coordinated boiler-turbine control based on nonlinear feedforward and linear feedback has been designed. Its parameters are adjusted by simulation.

8.2 Ship dynamics and control (C Källström)

A project in collaboration with SSPA (The Swedish State Shipbuilding Experimental Tank), where process identification techniques have been applied to determine ship dynamics, was finished during the year. The program package LISPID for parameter estimation in linear state space models has been used to analyse measurements from two different cargo ships and from 255 000 dwt oil tankers. The measurements of the tankers were performed in collaboration with Kockums Mekaniska Verkstad AB and the Salén Group. The program LISPID, which is running on the computer UNIVAC 1108 at Lund Computer Center, has also been used by SSPA in Gothenburg by tele-processing. A description of the program LISPID and results of identification are shown in the final report of this project, Åström-Norrbin-Källström-Byström (7431).

A joint project with Kockums Mekaniska Verkstad AB to design an adaptive autopilot for large oil tankers has been in progress during the year. The purpose of the autopilot is to keep the ship on the desired course and to perform course changes at different speeds and load conditions, and when the ship is disturbed by wind and waves. The preliminary experiments, described in the last annual report, have been followed by new ones on the tanker Sea Swift, owned by the Salén Group. The results so far have been quite satisfactory and further experiments with an adaptive autopilot will be carried out.

The ship simulation program, implemented by use of the interactive simulation package, SIMNON, has been improved. The program has turned out to be a very valuable tool to test different kinds of autopilots and to prepare full-scale experiments of ships.

8.3 Environmental problems

8.3.1 Wastewater treatment (G Olsson)

This work is performed in cooperation with Datema AB, Nynäshamn.

Most effort has been devoted to modeling and identification work of activated sludge processes. Biological models for activated sludge systems has been studied and the results have been written up in Olsson (7511C). Static as well as dynamical analysis of those models have been made. The influence of certain process parameters and different bacteria cultures have been studied. Those simulation results have been used to design identification experiments on the Käppala wastewater treatment plant in Stockholm. The simulation studies will be presented in forthcoming reports.

The identification results have been used to design control schemes for the control of dissolved oxygen content in the aeration tank of an activated sludge system. The oxygen control loop was closed during the spring 1975 and the digital control has been running hitherto in about 2 months. Both PI controllers and self-tuning regulators are programmed. Long time tests will be performed before any definite answers can be given about the consequences of the control.

During the fall 1974 G Olsson made a study tour to the USA to visit a workshop on Research needs for Automation of

Wastewater treatment systems. The trip has been reported in a travel report Olsson (7522C).

An MS thesis, Larsson-Schröder (RE146), was finished during the fall 1974. A model of sedimentation tanks was derived. The model has been simulated and compared to experimental results found in the literature.

8.3.2 Urban sewer flow dynamics (B Beck)

Last year a work was initiated to study prediction of urban sewer flow. Rainfall data for Stockholm and sewer flow data for the Käppala wastewater treatment plant were collected in 1974. Different predictors to estimate the parameters for the rainfall/sewer flow relationships have been tried out. The findings are reported in Beck (7432C).

8.3.3 River quality dynamics (B Beck)

The river quality modeling project was reported in the last annual report and has continued until the end of 1974, when Bruce Beck returned to Cambridge, England. Identifications of the dynamics of algal populations and their interactions with the dissolved oxygen (DO) and biochemical oxygen demand (BOD) in a fresh-water stream have been performed. The program packages IDPAC and LISPID have been used for this purpose. Some further results have been reported in Beck (7502C).

8.4 Climatized buildings (L H Jensen)

The work during the year can be summarized with the following items. The amount of time that has been spent on each item is also given.

Computer control of roomair temperature with heated air (water to air heatexchanger, 3 man months)

Computer control of roomair temperature with heated air (electrical airheater, 1 man month)

Computer control of inlet airtemperature (electrical airheater, 1 man month)

Development of a parameter free and gain independent regulator with no steady state error (1 man month)

Work with the final report (6 man months)

The first item deals with ventilated room. The inlet air is treated by a postheater. The heat is supplied by water. The normal pneumature control consists of two dampers which lead one part of the air-flow through the heatexchanger and the other part around it. The water-flow is constant in this case. This control was compared with different types of on/off control of the water-flow using a magnetic valve. In this case the whole air-flow passed the heatexchanger. The experiments showed that on/off control of the water-flow could be used to control the roomair temperature. The work is documented in Jensen-Hänsel (7421). The work has also been a part of a cooperation with the Swedish Steam Users's Association, Malmö.

The second item deals with on/off control of air temperature with an electrical airheater. Both pure on/off control and regulators using a model of the process were tested. A good result was achieved when a dead-beat regulator was used to indicate if the heading effect should be turned on or off.

The third item deals with control of inlet air temperature. The controlled process was an electrical airheater. The experiments were mainly carried out to test a simple parameter free and gain independent regulator with no steady state error.

This digital regulator is very suitable to use to control linear processes with unknown gain or slowly varying gain. The disturbances acting on the process are assumed to be rather slow. A certain class of nonlinear processes can also be controlled. The restrictions are that the process output and the process input are not allowed to change sign. This can always be overcome by proper scaling. Further the local gain must be in the interval between zero and two of the global gain. The regulator can be written as

$$u(t) = u(t-1)\ y_{set}/y(t)$$

where

$u(t)$	= process	input	new
$u(t-1)$	= "	"	old
$y(t)$	= process	output	actual
y_{set}	= "	"	desired

The quotient between the old process input u(t-1) and the actual process output y(t) can be interpreted as the inverted process gain. This number multiplied with the desired output gives the new input. It can also be seen that the new input u(t) will be equal to the old input u(t-1) only if the desired and the actual output are equal. This means that there will be no error in steady state. The only variable that has to be chosen is the sampling interval. The "50% time" of the stepresponse is a suitable value.

The major part of the work has been the writing of the final report which will be published in January 1976.

8.5 Profile control of a diffusion process (B Leden)

The process is a pilot plant in the laboratory. Process inputs u_1 and u_2 are the end temperatures of a long copper rod. Process outputs are the temperatures $y_1, y_2, \ldots, y_7$ in seven equidistant points on the rod. The process has been described earlier (report 7010).

The multivariable dead-beat controllers are used to drive the profile of the rod from an arbitrary initial state to a given equilibrium state in a minimum number of time steps. The controllers are computed from lumped models of the rod. The state of these models are either measured directly or reconstructed from the measured end temperatures y_{e_1} and y_{e_2} of the rod, using Kalman filtering techniques. The study shows that the profile of the rod may be controlled accurately in both cases, see Fig 8.1.

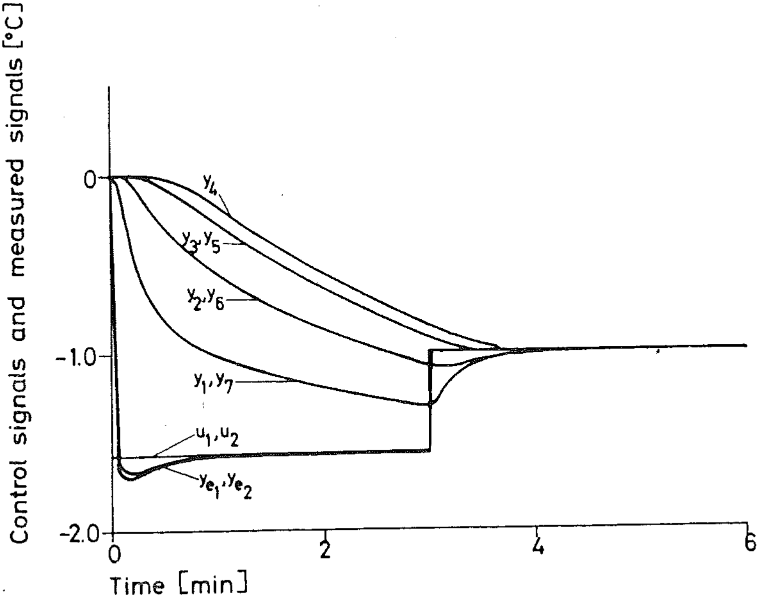

Fig 8.1 A multivariable dead-beat control experiment. The signals required to run the controller are measured directly. All temperatures are referred to 25.0°C.

The investigation also shows that there is no need to use very elaborate models of the rod for control purposes. This is explained by the fact that the use of dead-beat controllers makes it possible to employ a relatively long sampling period, compared to the sampling period required by conventional DDC-controllers. Therefore, it is not necessary to describe the fast dynamics of the rod accurately. In fact this points at one very interesting feature of the dead-beat controllers. Moreover, it is found that it is possible to construct dead-beat controllers for the diffusion process which meet very restrictive requirements on the maximal permissible magnitude of the control signals. These controllers are obtained by choosing a long sampling period. This work is reported in Leden 7508.

8.6 Biomedical problems (Per Hagander)

Work was done in Tuscon and Los Angeles during Febr to Aug 1974 on microcirculation, pharmacokinetics, cell cycle kinetics and control of respiration. The activities are documented in Hagander (7426C).

The cell cycle results have been further developed, and some aspects of the accuracy when doing identification and stochastic simulation of those compartment systems are investigated.

The microcirculation studies are continued together with Department of Experimental Medicin at Pharmacia. Measurements have been used to estimate the parameters of a model for the transport of macromolecules across the capillary membrane, see Rutili et al (1975a, 1975b).

Studies are going on at the Department of Experimental Surgery, Malmö, aiming at the control of local blood flow during cancer therapy. The results from XE-clearence experiments in dogs are being evaluated.

8.7 Miscellaneous

A dynamic model of a de-aerator of the boiler in a turbine tanker has been derived in an MS-thesis by Holmberg-Larsson (RE-152). During certain operating conditions pressure oscillations could occur in the de-aerator system. The purpose of the work was to find better control methods to avoid the oscillations. A mathematical model of the de-aerator with its exhaust system was built up and simulated and different control schemes were tried out. A significant improvement of the control system could be made.

A nonlinear model of the feed water system of a 250 000 ton dwt turbine tanker has been developed in an MS-thesis by Bramsmark-Bäckström (RE-155). The model has been simulated using the program package SIMNON and the behaviour of the model has been compared with measurements. Using the model different types of control strategies have been investigated.

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APPENDIX A, LIST OF PERSONNEL

Professor	Karl Johan Åström
Universitetslektor	Gustaf Olsson
Universitetslektor	Björn Wittenmark
Forskningsingenjörer (Research engineers)	Leif Andersson
	Gunnar Bengtsson (on leave in USA and Canada from Oct 1 1974)
	Ulf Borisson
	Hilding Elmqvist (half time assistant)
	Tommy Essebo (programmer)
	Jan Holst
	Ivar Gustavsson
	Torkel Glad (half time assistant)
	Lars Jensen
	Claes Källström
	Lennart Ljung (on leave in USA from Oct 1 1974)
	Sture Lindahl (with the Swedish Power Board since 1975)
	Staffan Selander (with Gränges Data since 1974)
	Tomas Schöntal (programmer)
	Johan Wieslander
Forskarassistent (Research assistant)	Per Hagander
Assistenter (Teaching assistants)	Bo Egardt
	Bo Leden
	Lars Pernebo
	Jan Sternby
Lab ingenjör (Laboratory engineer)	Rolf Braun
Tekn biträde (Technical drawings)	Britt-Marie Carlsson

Sekreterare (Secretaries)	Eva Schildt Marianne Moore
Srivhjälp (Typist)	Gudrun Christensen
Gästforskare (Visiting scientist)	Bruce Beck

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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 an operator console). August 1974.

RE-146 Larsson, R and Schröder, G: Dynamiska modeller för primärsedimentering i reningsverk (Dynamic models of primary sedimentation in waste water plants). September 1974.

RE-147 Andersson, G: Modeller och regulatorer för en industriell gasturbin (Models and regulators for an industrial gas turbine). May 1974.

RE-148 Åkerberg, E: Dimensionering av servosystem - en tillståndsmetod (Compensation of a servo system using a state space approach). October 1974.

RE-149 Cromnow, T: Dead-beat styrning av en värmediffusionsprocess (Dead-beat control of a heat diffusion process). October 1974.

RE-150 Fridolf, O: Reglering av fryshus (Temperature control in a freezing room). November 1974.

RE-151 Frideen, L: Atlas Copco Central Regulator RD100. Electronics and Systems (in English). December 1974.

RE-152 Holmberg, P and Larsson, J: Dynamiska modeller samt simulering och reglering av ångavluftarsystem på en turbintanker (Dynamic models, simulation and control of deaerator system on a turbine tanker). January 1975.

RE-153 Johansson, H A: Numerisk lösning av optimala styrproblem via generaliserade multiplikatorfunktioner (Numerical solution of optimal control problems using generalized multiplier functions). February 1975.

RE-154 Aspernäs, B and Foisack, P: Simulering av styrsystem för tankfartyg (Simulation of control systems for tankers). March 1975.

RE-155 Bramsmark, G and Bäckström, P: A nonlinear dynamical model and control of the feed water system on a turbine tanker (in English). April 1975.

RE-156 Jeppsson, O: En självinställande regulator för satsprocesser (A self-tuning regulator for batch processes). June 1975.

RE-157	Nordström, C: Simulering av märk- och brännportal (Simulation of a marking and welding machine). June 1975.
RE-158	Söderquist, B: TSX-tidsdelat operativsystem för PDP-15 (TSX - Poor man's timesharing). June 1975.
RE-159	Abramowicz, H and Stymne, K-J: Duala regulatorer (Dual adaptive regulators). June 1975.
RE-160	Björck, A: Interaktiv programmering vid flera användare (Interactive programming for several users). April 1975.

APPENDIX F, COURSES AND SEMINARS

The courses and seminars given are summarized in this appendix.

COURSES

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

The Theory of Dynamical Systems (Professor H Blomberg, Helsinki University of Technology, Otaniemi, Finland, Professor R E Kalman, University of Florida, Gainesville, USA, Professor H H Rosenbrock, Manchester, England, and Professor W M Wonham, University of Toronto, Canada).

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

Biological Systems (P Hagander, Department of Automatic Control).

Probability Theory (The book by Kai Lai Chung has been studied).

Cold Mill Automation (Dr G F Bryant, Imperial College, London, England).

SEMINARS

Professor S K Mitter, MIT, Cambridge, Mass, USA. "Controllability, Observability, Stability and Stabilizability of Systems with Time Delay", July 30, 1974.

Professor J B Moore, University of Newcastle, Australia. "Adaptive Estimation Using Parallell Processing Techniques", September 6, 1974.

Professor R Brockett, Harvard University, Cambridge, Mass, USA. "The Geometry of Rational Functions", September 16, 1974.

"Nonlinear Systems via Lie Algebraic Techniques", September 17, 1974.

Mr S Lindahl, Vattenfall, Stockholm.
"Reglering av värmekraftstationer" ("Control of thermal power plants"), September 19, 1974.

Professor S Morse, Yale University, New Haven, Conn, USA.
"Parametrization of Linear Systems for Identification", September 20, 1974.

Mr G Andersson, Stal-Laval, Finspång.
"Reglering av gasturbin" ("Control of a gas turbine"), November 13, 1974.

Professor G Einarsson, Lund Institute of Technology.
"Kommunikationsteori" ("Communication theory"), December 4, 1974.

Dr B Beck, visiting fellow from Cambridge University, England. "Some Problems of Water Pollution", December 10, 1974.

Dr B Wittenmark, Lund Institute of Technology.
"PR-resa med STURE" ("A round-trip with STURE"), December 12, 1974.

Mr O Fridolf, Accuray, Lund
"Reglering av fryshus" ("Control of a cold-storage plant"), December 19, 1974.

Mr E Ulén and coworkers, Research Institute of National Defense, Stockholm. "Presentation av forskningen vid avd 220 på FOA" ("Presentation of the research program of department 220 at the Research Institute of National Defense"), January 8, 1975.

Mr J Agerberg,
"PASCAL - ett programmeringsspråk" ("PASCAL - a programming language"), January 16, 1975.

Mr I Dahlstrand,
"Portabilitet hos beräkningsprogram" ("Portability of computing programs"), February 7, 1975.

Mr L Pernebo and Prof K J Åström, Lund Institute of Technology. "Classical Design", February 7, 1975.

Mr P-E Mases, Kockums, Malmö.
"Hur Kockums löser sina reglerproblem" ("How Kockums solve their control problems"), February 13, 1975.

Mr P-O Börjesson, Lund Institute of Technology.
"FFT och DFT. Diskussion av egenskaper och tillämpningar" ("FFT and DFT. A discussion of qualities and applications"), February 14, 1975.

Mr J Gertler, Budapest, Hungary.
"Standardization Efforts in Process Control", March 17, 1975.

Mr S Jahnberg, FOA, Stockholm.
"Tillförlitlighet hos datorer" ("Reliability of computers"), March 20, 1975.

Mr G Andersson, Elektronlund, Lund
"Hur vi gör reglersystem" ("How we make our control systems"), March 21, 1975.

Mr B Aspernäs and Mr P Foisack, Lund.
"Simulering av styrsystem för tankfartyg" ("Simulation of steering systems for tankers"), April 2, 1975.

Mr H Rundqvist, Lund Institute of Technology.
"Intellec samt uppbyggnad av ett mikrodatorkort" ("Intellec and the shape of a micro computer card"), April 3, 1975.

Professor B L Pierson, Iowa State University, Ames, Iowa, USA. "Optimal Control of Some Sailplane Trajectories", April 4, 1975.

Mr H Elmqvist, Lund Institute of Technology.
"INTRAC - ett interaktivt språk" ("INTRAC - an interactive language"), April 7, 1975.

Mr B Holm, ASEA, Västerås.
"Presentation av processdatorn Modcomp" ("Presentation of the process computer Modcomp"), April 11, 1975.

Dr D Clarke, University of Oxford, England.
1) "Self-tuning Controllers", April 16, 1975.
2) "Micro-processor Self-tuners", April 18, 1975.

Mr H Elmqvist, Lund Institute of Technology.
"SIMNON-nyheter" ("SIMNON-news"), April 21, 1975.

Mr L Jensen, Lund Institute of Technology.
"Reglerproblem inom värme och ventilation" ("Control problems in air-conditioning"), April 23, 1975.

Mr I Aaro, Royal Institute of Technology, Stockholm.
"Ett hjälpmedel för interaktiv kommunikation mellan människa och program" ("An aid for interactive communication between man and program"), April 28, 1975.

Dr J W Bernard, The Foxboro Company, Mass, USA.
"Research at Foxboro", May 5, 1975.

Dr B Leden, Lund Institute of Technology.
"Identifiering och dead-beat-styrning av en värmeledningsprocess" ("Identification and dead-beat-control of a heat diffusion process"), May 20 and 21, 1975.

Professor R Mehra, Harvard University, Cambridge, Mass, USA.
"System Identification", May 27 and 28, 1975.

Ing A Halouskova, Institute of Information Theory, Prague, Czechoslovakia. "Effective Algorithms for Least Squares", May 30, 1975.

Dr O Sefl, Institute of Information Theory, Prague, Czechoslovakia. "Research in Prague", June 3, 1975.

APPENDIX G, LECTURES BY THE STAFF

1974

July 10	B Wittenmark: Industrial applications of a self-tuning regulator. Systems Control, Palo Alto, USA.
July 11	B Wittenmark: Industrial applications of a self-tuning regulator. System Science, UCLA, Los Angeles, USA.
July 11	P Hagander: Operator factorization and the fixed interval linear smoothing problem. Systems Science, UCLA, Los Angeles, USA.
July 15	K J Åström: Theory and applications of self-tuning regulators. Univ of Manchester, Manchester, England.
July 15	P Hagander: Review of five papers on exercise and respiration. Dept Anesthesiology, UCLA, Los Angeles, USA.
July 30	B Wittenmark: Adaptive control - A survey. Brown University, Providence, USA.
Aug 5	B Wittenmark: On self-tuning regulators. Harvard University, Cambridge, USA.
Aug 8	B Wittenmark: Self-tuning regulators - Theory. Brown University, Providence, USA.
Aug 13	B Wittenmark: Self-tuning regulators - Industrial applications. Brown University, Providence, USA.
Aug 26	B Wittenmark: On self-tuning regulators. University of Montreal, Montreal, Canada.

Aug 27	B Wittenmark: Industrial applications of a self-tuning regulator. Canadian Pulp and Paper Research Institute.
Sept 9	K J Åström: System modelling for control and optimization. Institut de la vie Conférence Mondial Vers un plan d'action pour l'Humanité, Paris.
Sept 25	K J Åström and B Wittenmark: Analysis of a self-tuning regulator for non-minimum phase systems. IFAC Symposium on Stochastic Control, Budapest.
Sept 27	U Borisson: Self-tuning control of an ore crusher. IFAC Symposium on Stochastic Control, Budapest.
Sept 27	L Ljung: Analysis of a class of adaptive regulators. IFAC Symposium on Stochastic Control, Budapest.
Sept 27	L Ljung: Convergence of recursive stochastic algorithms. IFAC Symposium on Stochastic Control Theory, Budapest.
Sept 27	K J Åström: Stochastic control theory and some of its industrial applications. Invited general lecture, IFAC Symposium on Stochastic Control, Budapest.
Oct 1	K J Åström: System identification. Technical University of Budapest, Budapest, Hungary.
Oct 2	K J Åström: Self-tuning regulators. Hungarian Academy of Science, Budapest, Hungary.
Oct 3	G Olsson: Control problems in wastewater treatment systems. MIT, Electronic Systems Lab, Cambridge, Mass, USA.

Oct 3	K J Åström: Computer aided design of control systems. Computer and Automation Institute, Hungarian Academy of Science, Budapest, Hungary.
Oct 10	T Glad: Lagrange multiplier methods for nonlinear optimization. IFAC/IFORS Conference on Optimization - Applied Aspects, Varna, Bulgaria.
Nov 20	P Hagander: Användning av dynamiska modeller vid biologisk forskning (The use of dynamic models in biological research). Avd för experimentell medicin, Pharmacia, Uppsala.
Nov 25	G Bengtsson: Identification of linear systems. Three lectures given at the Center for Mathematical System Theory, Univ of Florida, Gainesville, Florida, USA.
Dec 5	L Ljung: Optimal control of a sulfite digester. Measurex, Inc, Cupertino, Calif, USA.
Dec	G Bengtsson: Geometric state space theory. Three lectures given at the Center for Mathematical System Theory, Univ of Florida, Gainesville, Florida, USA.
Dec 17	J Holst: Användande av självinställande prediktorer för prognos av belastning i kraftsystem (On the use of self-tuning predictors for prediction of the hourly load in a power network). Statens Vattenfallsverk (Swedish State Power Board), Stockholm.

1975

Jan 13	L Ljung: Convergence of recursive stochastic algorithms. Stanford University, Stanford, Calif, USA.
Jan 20	L Ljung: Identification of systems with feedback. Systems Control, Inc, Palo Alto, Calif, USA.
Feb 3-4	I Gustavsson: Praktisk tillämpning av processidentifiering (Application of process identification). Institute of Technology, Uppsala.
Feb 24	L Ljung: Identification of systems with feedback. ISL Industrial affiliates meeting, Stanford University, Stanford, Calif, USA.
March 18	K J Åström: Processidentifiering (System identification). Institutionen för statistik, Göteborgs Universitet.
March 19	K J Åström: Statistisk reglerteori (Stochastic control theory). Institutionen för statistik, Göteborgs universitet.
March 20	G Olsson: Modellbyggnad och reglering av aktivslamanläggning (modeling and control of an activated sludge process). Föreningen för Vattenhygien, Royal Inst of Technology (Swedish section of Water Pollution Control Federation), Stockholm.
March 25	K J Åström: System identification and adaptive control. Univ of Stuttgart.
April 4	G Bengtsson: Feedforward control of linear multivariable systems. Dept of Electrical Engineering, Univ of Toronto.
April 21	L Ljung: Adaptive control. Stanford university, Stanford, Calif, USA.

April 17 K J Åström: Gyroskop som mätgivare (The gyro as a transducer). Department of Electrical Measurements, Lund Institute of Technology.

April 21 and 23 L Ljung: On the significance of conditioning, innovations and martingales in identification problems. Stanford University, Stanford, Calif, USA.

April 24 K J Åström: Kalman-filtrering - en teori för dynamiska mätningar (Kalman filtering - a theory for measurement of dynamic variables). Department of Electrical Measurements, Lund Institute of Technology.

May 22-23 Interactive data handling of dynamical systems. Course for industrial and university people given in Lund.

1) Inledning (introduction), K J Åström.
2) Interaktiv databehandling (Interactive computation), J Wieslander.
3) IDPAC - ett interaktivt program för dataanalys och identifiering (IDPAC - an interactive program for data analysis and identification).
4) Industriella tillämpningar av IDPAC (Industrial applications of IDPAC): Ship dynamics, K J Åström and C Källström, Wastewater treatment plants, G Olsson.
5) SIMNON - ett interaktiv simuleringsprogram för olinjära system (SIMNON - an interactive simulation program for non-linear systems).
6) Tillämpningar av SIMNON (Applications of SIMNON): Simulering av en kraftstation (Simulation of a power station), S Lindahl, Swedish State Power Board, Farmakokinetik (Farmacokinetics), K J Åström and G Wettrell (Lund University Hospital), Synkroniseringsregulator till tryckpress-

linje (Synchronization controller for a printing machine set-up), Göran Andersson.

7) Datorstödd syntes av reglersystem (Computer aided design of control systems), J Wieslander.

8) SYNPAC - ett interaktivt programsystem för syntes av reglersystem (SYNPAC - an interactive program system for synthesis of control systems), J Wieslander.

9) Dimensionering av styrautomater för flygplan (Synthesis of autopilots for aircrafts), P O Elgcrona, SAAB-SCANIA.

10) CDP - classical design package - classical synthesis, Beatrice Shearer, Imperial College, London.

11) Kombination av simulering och optimering för syntesändamål (Combination of simulation and optimization for synthesis purposes), T Glad.

12) Implementering av interaktiva program (Implementation of interactive programs), J Wieslander.

June 4 L Andersson: Program development for microcomputers using a host computer. MIMI 75, Mini- and microcomputers and their applications, Zürich, Switzerland.

June 6 K J Åström: Teori och teknologi (Theory and technology). IVA Troedsson Symposium, Skövde.

June 10 L Ljung: On consistency and identificability. Symposium on Stochastic Systems, University of Kentucky, Lexington, Kentucky.

APPENDIX H, TRAVELS

Karl Johan Åström spent part of the summer at Imperial College, London, with trips to Cambridge, Manchester and Oxford. He also participated in Institut de la Vie Conference on "Vers un plan d'actions pour l'Humanite", the IFAC Symposium on Stochastic Control, Budapest, and the Heads of Control Laboratories meeting in Rome.

Gunnar Bengtsson has been on leave from October 1974 in USA and Canada. During the period Oct 1, 1974 - Jan 4, 1975 he has visited University of Florida, Gainesville, USA, and after that the University of Toronto, Toronto, Canada. He also participated in the IFAC Symposium on multivariable systems in Manchester, England, in Sep 1974.

Ulf Borisson participated in the IFAC Conference on Stochastic control theory in Budapest in Sept 1974.

Torkel Glad participated in the IFAC/IFORS conference on Optimization - Applied Aspects in Varna, Bulgaria, October 1974.

Per Hagander visited UCLA, Los Angeles, USA, from March until the end of August 1974. This is reported in Hagander (7426 C).

Claes Källström was travelling with the tanker Sea Swift from Dubai to Cape Town Oct 5 - Oct 24, 1974. During the travel, experiments with the autopilot were tried out.

Lennart Ljung has been on leave from the Department from October 8, 1974, and has visited Stanford University, Stanford, California. He is expected to return in October 1975. He also participated in the IFAC Symposium on Stochastic Control Theory in Budapest in September 1974. He has been visiting the Information Systems Laboratory, Stanford University, Stanford, Calif, since October 1974.

He participated in the IEEE Conference on Decision and Control in Phoenix, Arizona, November 1974, and in the Symposium on Stochastic Systems in Lexington, Kentucky, June 1975.

Gustaf Olsson participated in a workshop on research needs in automation of wastewater treatment, held in Clemson, South Carolina, USA, in Sep 1974. He also visited some other research institutes during the same travel. It is reported in a travel report, Olsson (7522C).

Johan Wieslander participated in the IFAC symposium on multivariable systems, Manchester, England, in Sep 1974.

Björn Wittenmark returned from University of Calgary, Canada, and the Brown University, Providence RI, USA, in the end of August 1974, where he had been since Feb 27, 1974. The visits are reported in Wittenmark (7429C).