Activity Report: Automatic Control 1975-1976

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LTH

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ABSTRACT

The report gives a survey of the activity at the Department of Automatic Control during the academic year 1975-1976. It also summarizes the undergraduate education (civilingenjörsutbildning) and the control laboratory facilities. At the civilingenjör level (≈ MS) five different courses are given on a regular basis. About 450 students have participated during the year. Also 31 MS-theses and 2 PhD theses have been completed.

The areas of research are system identification, adaptive control, computer aided design of control systems and linear systems theory. The applied research covers ship steering control, wastewater treatment control, climatized building control as well as bio-medical systems.

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Notice

References to publications are given in two different forms. Published papers are listed in Appendix B and are referred to by author's name and year. Technical reports are listed in a new code system from this year, the International CODEN System. Reports completed after July 1976 will be available from official libraries, like the Lund University Library. All technical reports are referred to by the authors name and the code TFRT-XXXX and are listed in Appendix C.

1. INTRODUCTION

This report follows the pattern of the previous yearly activity reports. The purpose is to give an up to date overview of the activity. In this year's issue the section 2 on education has been expanded for the benefit of our foreign collegues who are not familiar with the Swedish system of engineering education. Because of the continuity of research the major research programs are similar to those of the previous years.

This year it was felt that industry's awareness of the potentials of interactive computing is increasing. We believe this to be significant because we have ourselves noticed the significant impact of the interactive packages in our own work. We also believe that the results on self-tuning regulators should be of interest for persons engaged in applied control problems. Indications of substantial benefits from the adaptive technique have e.g. been observed in the projects on ship steering and on climate control.

We will also show our appreciation to the Swedish Board of Technical Development (STU), the Swedish Institute of Applied Mathematics (ITM), the National Board of Building Research (BFR), and the Scandinavian Council for Applied Research (Nordforsk), who have supported several of our projects.

2. EDUCATION

A summary of the course and laboratory works at the civilingenjör (≈ MS) level as well as the PhD level are given. During the year also continuing education has been arranged.

2.1 Civilingenjör program

The Department of Automatic Control is responsible for all education in control. Although the department belongs to the School of Physics (F) courses are also given to the Schools of Electrical Engineering (E), Mechanical Engineering (M), and Chemical Engineering (K). The students will have the first course in control during their third or fourth year. The control courses are taken in parallel with other subjects. There are five different courses available for the students, some of which are compulsory. Before the civilingenjör degree (which corresponds to an MS) every student has to complete a thesis in some of the major subjects, e.g. control. The nominal time for the thesis is 3 months full time work. It could be performed by either single students or by groups of two students.

2.1.1 Courses

A brief presentation of the content of courses now follows.

(1) Linear systems (allmän kurs). (Compulsory for F, E, and M; about 250 students.) The course is given during one semester in the third or fourth year. It includes 28 hours lectures, 14 hours problem solving sessions in smaller groups, and 14 hours laboratory work.

Main content: Linear continuous systems described in state space or by transfer functions. Frequency analysis, classical design, stability theory for linear systems, state feedback, state reconstruction.

Literature: K J Åström: Reglerteori (Control theory), Almqvist & Wiksell, 2 ed. 1976.
Problems and solutions.

Each year there usually is a special project group of 10-15 students. The group consists of students with special interest in control who make a smaller project work in parallel with the ordinary course. Last year the group investigated a temperature control system, see TFRT-7090.

(2) Control theory for chemical engineers (mindre kurs) (Compulsory for about 50% of K-students, about 50 students.) The course is given during one quarter in the fourth year. It contains 21 lecture hours, 14 problem solving sessions but no laboratory work.

Main content: Process model building, process dynamics, linear continuous system, transfer functions, classical design techniques.

Literature: G Olsson: Reglerteknik för kemister (Chemical engineering process control), lecture notes. Problems and solutions

(3) Advanced course (fortsättningskurs) (Optional for F and E, about 50 students.) The course is given during one semester in the fourth year. It contains 42 lecture hours, 28 hours problem solving sessions, and 14 hours laboratory work.

Main content a): Nonlinear systems. Phase plane analysis, Lyapunov theory, describing function method.

Literature: K J Åström: Olinjära system (Nonlinear systems), lecture notes.

Main content b): Sampled data systems. Linear sampled systems described in state space or in input-output relations. Stability theory, dead beat strategies, state feedback, state reconstruction.

Literature: K J Åström: Samplade system (sampled data systems), lecture notes.

Main content c): Stochastic systems. Description of stochastic processes, mostly in discrete time. Analysis of linear systems with stochastic inputs, synthesis

of stochastic systems, minimum variance strategies.
Literature: K J Åström: Stokastiska system (Stochastic systems), lecture notes.

(4) Systems engineering (reglerteknik-systemteknik)
(Optional for M, 10-15 students.) The course is given during one semester during the fourth year. It contains 42 lecture hours, 28 hours of problem solving sessions (in small groups), and 14 hours of a project work. The course is based on the course in linear systems (1) but is less theoretically oriented than the advanced course (3).
Main content: Survey of the theory of time-discrete linear systems and stochastic systems. Applications in inventory control, power systems, industrial economics.
Literature: G Olsson and B Wittenmark: Lecture notes in systems engineering.
The two projects of last year have been Control of a heat exchanger in the food industry (see TFRT-7103) and Simulation of an industrial production system (see TFRT-7102).

(5) Computers in control systems (datorer i reglersystem)
(Optional for F, E, M, and K; about 75 students.)
The course is given during one semester in the fourth year. It contains 28 lecture hours, 14 hours problem solving and programming sessions in smaller groups, and 14 hours laboratory work at process computers.
Main content: Hardware organization of a process computer, process and peripheral interfaces. Interrupt handling. Real time programming, executive systems for process control, process oriented languages.
Literature: J Wieslander: Datorer i reglersystem (Computers in control systems), lecture notes.

2.1.2 Master theses

During the year 23 master theses have been completed by 31 students. The abstracts of the theses have been presented in a separate report, Wittenmark TFRT-6007. A list of the reports is given in Appendix C. Most of the reports are written in Swedish with an English abstract.

2.2 PhD program

The graduate program is a four year curriculum based on the MS (civilingenjör) degree. It leads up to the PhD degree (teknisk doktorsexamen). The graduate program is dominated by coursework during the first three or four semesters. Some of the courses are given as formal lectures and seminars, see Appendix D. Others are defined by books, lecture notes, published papers etc. and are presented in study groups or taken by single students.

During the academic year there has been 14 active full time PhD students. Two PhD theses have been completed:

Ulf Borisson: Self-tuning Regulators - Industrial Application and Multivariable Theory, Nov 1975. TFRT-1010. (See further Section 4.3.)

Torkel Glad: Constrained Optimization using Multiplier Methods with Applications to Control Problems, May 19, 1976. TFRT-1011. (See further Section 5.5.)

2.3 Control laboratory

The computer PDP 15/35 has been used about 5000 hours during the year. Its present configuration includes 32 k core memory, 256 k fixed head disk, a 1.2 M cassette disk memory with a PDP 11-05 CPU, 3 DEC tape units, 16 analog inputs, 8 analog outputs, 18 digital inputs and outputs. A line-printer Regnecentralen (10 lines per second) has also been used since the start 1970.

The computer has been used both for interactive programs (see chapter 5), remote control and real time calculations. It is used mostly for research purposes but to some extent in the education in the courses (3) and (5), see 2.1, and for master theses works.

An aircraft simulator has been built up during the year in a MS work by Hansson (TFRT-5175). The simulator consists of a surplus aircraft chair (Lansen) supplied with instruments for altitude, direction, horizontal gyro and speed. Hitherto only a linear model has been simulated on an analog computer.

During the year a room for display of components have been made ready. In the room there is some permanent displays but there is also space which make it possible for instrumentation companies to have temporary shows.

The rest of the available laboratory equipment is summarized here.

There are 6 analog computers which are constructed at the Department. They are used mainly for laboratory course works, but there is an increasing demand to use them also in research work as small simulators of real processes for computer control tests. Each computer consists of standard modules. In a standard version it consists of an instrument panel, a signal generator (triangle and square wave), 10 amplifiers (integrators or summators), 10 potentiometers and two multipliers. Noise generators are also available. There is a normal/fast operating speed, repetitive mode as well as sample and hold possibilities. The analog computer can be connected to a DC servo system with compensation networks, amplifiers and tacho generator.

A level control system, consisting basicly of three tanks in series, is available for the education. The three levels can be measured, and the flow can be controlled by two control valves, one before the first tank and one after the third tank. A flow meter and two PID controllers are also available. All measurement signals are connected to a panel and the actuators and controllers are also available there. The process can also be connected to a digital computer.

Four microcomputer systems have been used in different applications, particularly developed in MS theses (see further Section 7.5). Hitherto the systems Intel 4004, 4040, 8008, and 8080 have been used.

A mechanical system consisting of a rod with balancing balls is in use both for demonstration purposes and for computer control laboratory experiments.

A thermal system consisting basicly of a long copper rod was initially a PhD project by Leden (TFRT-1009). The inputs 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.

A simple pH control system can be used for demonstration purposes in the education. The purpose is to neutralize a mixture of a base and an acid. The high sensitivity of the system in connection with a long time delay makes the control not at all a trivial task.

A boiler simulator has been built up. The system is aimed to be a standard process for control experiments. There are four inputs and five outputs from the system, all available on a panel. Manual, analog or digital control can be applied to the system.

2.4 Continuing education

As during previous years, courses and contact meeting have been arranged in order to encourage and improve the contacts between the Department and the Industry and other external contacts.

A four day course on Interactive computation of dynamical systems was held on June 1-4, 1976, at the Institute. The course was split up into two parts, two days each. The first part was almost the same as a similar course the year before. The second part was a continuing course for a very limited number of people.

In the first part 55 people from industry and other research institutes participated. Three interactive program systems were presented, IDPAC for data analysis and identification, SYNPAC for system design and synthesis, and SIMNON for simulation of non-linear systems. The presentations were given in lectures and demonstrations at computer terminals for the Univac 1108 and PDP15 computers. The detailed program is listed in Appendix D. In the second part of the course only four people participated. During two days they had individual advice to use the programs at the computer. Separate problems were treated according to the different interests of the participants.

A course in control theory was started up in the fall 1974 at Kockums Mekaniska Verkstad AB, Malmö. This course has continued for 15 control engineers at the company and was finished in the fall 1975.

3. SYSTEM IDENTIFICATION

The research on system identification has continued in the following areas:

- identification of closed loop systems
- analysis of certain recursive identification schemes
- properties of prediction error identification methods
- numerical properties of fast algorithms for recursive identification

In most cases earlier results have been summed up and extended. The program facilities are still under development and are extensively used in applications. Examples are given in Section 7. The interactive program IDPAC was presented in a course for industrial people about interactive programs, see Appendix D and Section 2.4.

3.1 Identification of closed loop systems

The influence on the identifiability and on the accuracy of the estimates of different model structures, identification methods and experimental conditions have been studied. Most of these results have been reported in previous activity reports. Some results, however, have been generalized, Söderström-Ljung--Gustavsson (1976 b). A necessary and sufficient condition for identifiability is derived. It can be met by simple conditions on the regulators and the couplings from possible external input signals.

The available results for identification of closed loop systems have been summarized in Gustavsson-Ljung-Söderström (1976) as an invited survey for the 4th IFAC Symposium on Identification and System Parameter Estimation, Tbilisi, 1976, where an extensive literature survey is given. The ideas have been applied to the identification of ship steering dynamics, cf. Section 7.1, and to the identification of a laboratory process.

3.2 Analysis of recursive stochastic algorithms

The approach to analyse convergence of stochastic algorithms using a deterministic differential equation has been described in earlier annual reports. Some extensions to dynamic generation of the observations, to allow, e.g., treatment of general adaptive systems are given in Ljung (TFRT-3096) and in Ljung (TFRT-7097). Applications to Landau's identification scheme, the extended least squares method and the self-tuning regulator, with a classification of the role of positive real transfer functions in this context are given in Ljung (TFRT-3138).

The Extended Least Squares method for estimation of the parameters in an ARMA process have been analysed using the above mentioned deterministic differential equation. Let the process be described by

$$A(q^{-1})\ y(t) = C(q^{-1})\ e(t)$$

where the noise $e(\cdot)$ is supposed to be white, and the polynomials $A(z)$ and $C(z)$ relatively prime, asymptotically stable and of order n_a and n_c respectively. If the parameters are unknown but the assumption of the system order correct, the only stationary point to the differential equation, i.e. the only convergence point to the algorithm is the true values of the parameters. It is however known that the algorithm does not always converge, i.e. this stationary point is not always stable.

The properties of the linearization of the differential equation around this stationary point have been studied. The analysis leads to explicit expressions for the eigenvalues of the system matrix for the linearized equation. They are

-1 of multiplicity n_c

$-1/C(\alpha_i)$ $i = 1,\ldots,n_a$,

where α_i are solutions to the equation

$$z^{n_a} A(z^{-1}) = 0.$$

The analysis method is possible to extend to other recursive identification methods, but only preliminary results are available.

3.3 Prediction error identification methods

Consistency analysis of so called prediction error identification methods has been described in previous annual reports. Some work in this area has continued. It has been shown that the obtained estimates are asymptotically normal, regardless of the distribution of the inputs and outputs, Caines-Ljung (1976). Explicit formulas for the asymptotic variance of the estimates are also given, and it has been shown that the best accuracy is obtained if the determinant of the sample prediction error covariance matrix is minimized with respect to the unknown parameters.

Consistency results have also been applied to the least squares identification method, Ljung (1976a), and to detection problems, Kailath-Ljung (1976c).

3.4 Consistency for the least squares identification method

The method of Least Squares (LS) is the most basic and simple identification method, and it is therefore important to understand all the different aspects of it very well. In

Sternby (TFRT-7104) the Bayesian point of view is used, i.e. the fine parameters are considered as random variables. The main result is a necessary and sufficient condition for consistency with probability one, which in the open-loop case is similar to, but somewhat weaker than the condition of persistently exciting input. The distributions of the noise sequences and the parameters are supposed to be Gaussian, but on the other hand no condition on the stability of the system is needed, as is the case for previous results.

3.5 Fast algorithms

During the last few years there has been a growing interest in so called fast algorithms. The principle is that calculations proportional to n^2 are reduced to calculations proportional to n, where n is the number of unknown parameters. For recursive identification, however, it means that the covariance matrix is not computed, which sometimes is a disadvantage. Only very little practical experience of these algorithms exists so far.

During Ivar Gustavsson's visit at Stanford University, California, a preliminary investigation of a fast version of the recursive least squares methods was initiated. The study so far has shown that even for few parameters numerical difficulties may occur. The estimates may diverge. Double precision improves the behaviour. Compared to the conventional recursive least squares algorithm this fast version is much more sensitive to the accuracy of the computations. However, it might be possible to get a better behaviour by modified algorithms.

4. ADAPTIVE SYSTEMS

Adaptive systems has been a major research area for several years. In order to distribute the knowledge about adaptive systems a graduate course was arranged during the spring semester. The course was later followed up with a seminar series on model reference systems given by prof I Landau, Grenoble, see Appendix D.

4.1 Dual control

The work on finding good suboptimal control strategies for systems with unknown and time varying parameters has continued. Consider the system

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

where the coefficients of the polynomials A* and B* are unknown stochastic processes. Then a reasonable criterion to minimize for steady state control is

$$\lim_{N\to\infty} \frac{1}{N} E\left[\sum_{t=1}^{N} (y(t) - y_{ref}(t))^2\right]$$

Since it is very difficult to minimize this criterion approximations have to be done. One possibility is to minimize over two steps only, i.e. to use the loss function

$$\frac{1}{2} E\left[\sum_{t=1}^{2} (y(t) - y_{ref}(t))^2\right]$$

Even with this loss function further approximations have to be done. Computer programs have been written to simulate and compare different suboptimal dual regualtors.

4.2 Self-tuning regulators

The approach to investigate convergence of the self-tuning algorithms using deterministic differential equations have been described in earlier reports. These results are used in Ljung (TFRT-3138) to show that the basic self-tuning regulator (see e.g. Wittenmark TFRT-3054) will converge to the minimum variance regulator with probability one if:

(i) The process is described by the model

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

(ii) The process is minimum phase

(iii) The filter $C^*(q^{-1})$ is positive real

(iv) The identification in the algorithm is done using a stochastic approximation method.

If the identification is done using the method of least squares then it must be assumed that the transfer function $1/C^*(q^{-1}) - 1/2$ is positive real. These results imply that the self-tuning regulators converge to the desired minimum variance regulator for a large class of systems.

In Ljung-Wittenmark (TFRT-7084) the stabilizing property of self-tuning regulators is discussed. It is shown that under fairly weak assumptions the closed loop system will be stable when using the self-tuning regulator. The main assumptions are that the open loop system is stable and minimum phase.

A summary of the properties of self-tuning regulators was presented at the IFAC World Congress in Boston, see Åström--Borisson-Ljung-Wittenmark (1975).

A master thesis project, see Kiziroglu (TFRT-5182), has resulted in the implementation of a self-tuning regulator on an Intel 8080. The programs takes about 1.4 K bytes. The execution time when tuning three parameters is about 100 ms (the instruction cycle time used is 1 μs).

4.3 Multivariable self-tuning regulators

The work on multivariable self-tuning regulators has resulted in a PhD-thesis, Borisson (TFRT-1010). A minimum variance strategy for multivariable systems has been derived, and it has then been shown that the simple self-tuning regulator for single-input single-output systems can be extended to the multivariable case with its simplicity retained. The class of systems is restricted to minimum phase systems having the same number of inputs as outputs and an impulse response starting with a nonsingular matrix. The result of the analysis also gives insight into the case, when several single-input single-output self-tuning regulators are operated in cascade mode.

The process to be controlled is assumed to be described by a linear vector difference equation including a moving average of white noise. At each sampling interval the self-tuning algorithm performs a least-squares estimation, and the obtained estimates are then used to compute the control signal. The parameters of the controller are equal to the estimated parameters. The estimation performed at each sampling interval is divided into a number of steps which is equal to the number of inputs. By letting the initial values of the covariance matrices in the least-squares identification be the same for these steps, the corresponding gain vectors will also be the same. In this way significant savings in the computations are obtained.

In spite of the restrictions on the class of systems, it is believed that the self-tuning regulator is of great practical interest, because there are many multivariable systems to which it can be applied. A typical case is the control of a head-box of a paper-machine, which is discussed in some detail.

4.4 Adaptive prediction

The problem of predicting an unknown stochastic process via real time estimation of the parameters in a process or predictor description have been further studied. When ARMA processes are considered there are different ways of choosing the parametric description of the problem. Apart from a model of the process where the parameters are estimated, different predictor representations may be used and the parameters therein estimated.

It has been shown that these predictors are equivalent as far as one step prediction is concerned. They are in fact related via a change of variables. When used for k step prediction there is however no such relation between all of the representations. For this case simulation studies show that the method where the process parameters are estimated and two of the methods where the parameters in the predictor description are estimated have a similar performance.

When the extended least squares method is used for the parameter estimation the sequence of estimates do not always converge. If it converges and some structural conditions are fulfilled the unique convergence point is the true values of the parameters irrespective of the structure of the predictor. A condition for local convergence to this point is established. This condition is expressed in terms of the parameters in the process to predict and is independent of the number of steps to predict.

In certain applications it is necessary to simultaneously predict 1,...,M steps ahead. If an adaptive predictor for each of these predictions is to be used the calculations might be rather timeconsuming. Simplifications using only the parameters estimated from the one step predictor have been obtained.

4.5 Adaptive smoothing

In Hagander-Wittenmark (TFRT-7091) it is shown how the idea of adaptive prediction can be used to determine an adaptive fixed-lag smoother. The problem discussed is the estimation of a discrete time stochastic signal which is corrupted by additive white measurement noise.

The fixed-lag smoother for known systems is first derived using polynomial operations. The optimal smoother involves a spectral factorization. When using the self-tuning smoother the computational difficulties with spectral factorization are avoided by direct estimation of the parameters in a prediction model.

The self-tuning smoother consists of two parts: An on-line estimation of the parameters in the one step ahead predictor of the measured signal and a computation of the smoother coefficients by simple manipulations of the predictor parameters. In simulations the smoother has appeared to have good transient as well as good asymptotic properties.

5. COMPUTER AIDED DESIGN

An extensive effort has been made during the last few years to transfer results and methods of identification, simulation and control system design into a form suitable for the use in applications.

A set of interactive command-driven programs to solve control system analysis and design problems have been presented in previous activity reports. The work has been continued during this year.

In another project constrained optimization methods have been applied to solve control problems.

An organized program exchange between a number of control laboratories has been initiated during the year by Nordforsk. This work is also described.

5.1 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 introducting 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.

5.2 The interactive programs for identification (IDPAC) and control synthesis (SYNPAC)

The program, IDPAC, for interactive datahandling and identification includes routines for data moving, scaling, trend elimination etc. Parameter estimation algorithms includes Maximum Likelihood and Least-Squares estimation of Multiple Input - Single Output system, correlation analysis, model analysis as well as statistical tests.

During the year, refinements have been made to the frequency response handling routines and to the least squares estimator. An IDPAC User's Guide has been compiled, Wieslander (TFRT-3099).

The program, SYNPAC, for synthesis of multivariable linear systems has been relatively untouched but work is in progress that will have great impact, below.

5.3 A model analysis package

A program for interactive analysis and transformation of system descriptions (models) is being constructed, MODPAC. Today it consists mainly of a set of loose ends. It will consist of routines for state space system transformation and decomposition (ready today) as well as routines to go from state space to transfer function or vice versa (things to come). MODPAC will greatly influence SYNPAC because of the more elaborate system description allowed.

5.4 Interactive simulation (Simnon)

The program package Simnon has been presented in previous activity reports. It is now available at the PDP 15/35 computer at the Department, the Univac 1108 computer at the Lund University Data Centre as well as the DEC 10 system at the Stockholm University Data Centre.

The Simnon program has been used frequently at the Department. There has then been demands for including new facilities. Some of these facilities have been thought of before but have not been implemented because of problems with the implementation when using FORTRAN.

There is a large need for interactive simulation programs. In order not to let problems with implementation influence the design of an interactive simulation language, it was decided to make a complete study about interactive simulation. The most important aspect is considered to be how a man as easily as possible can make a computer simulate. The implementation of such a program is considered as a secondary problem.

The study of interactive simulation has begun during the year.

The Simnon implementation on the Univac 1108 has been made significantly more efficient during the year. The internal compiler now produces machine code instead of pseudo code as an output. This results in a a significant reduction of the simulation time.

5.5 Constrained optimization and its applications to control problems

The work on combined multiplier and penalty function algorithms for constrained optimization has been continued. In Glad (TFRT-1011) convergence properties of different updating methods for the multipliers are studied and the results from Glad (TFRT-3092) are extended.

The use of combined multiplier and penalty functions in optimal control problems has also been investigated in Glad (TFRT-1011). The Hestenes-Powell updating rule for the multipliers is shown to have a linear convergence rate. The extension to mixed state and control inequality constraints is also considered and second order sufficiency conditions for an optimum are derived.

To show the applicability of parametric optimization to the design of controllers, a number of examples of such designs are presented in Glad (TFRT-1011). Another application is given in the MS-thesis by Holmberg and Svensson (TFRT-5168), where parametric optimization is used to design an output feedback controller for a boiling water reactor.

On-line use of optimization is investigated in the MS-thesis by Hedlund (TFRT-5173). Optimal adjustment of the parameters in controllers for a servo motor is obtained using an optimization algorithm on the PDP-15.

The possibility of using optimization algorithms in a micro computer is considered in Sixtenson (TFRT-5183). The algorithms considered are the Fletcher-Reeves method and direct search methods.

5.6 Presentation

The programs have been presented to presumtive users and to other people in the field on a number of occations, the main event beeing a contact meeting in Lund, June 1-2, 1976. 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 Appendix D.

5.7 Program exchange

An organized program exchange has been established during the year. A grant from NORDFORSK (The Scandinavian Council for Applied Research) has enabled the control laboratories in Lund (Sweden), Trondheim (Norway), Copenhagen (Denmark), and Helsinki (Finland) to form a group with the aim of boosting the idea of computer aided design in the field of Automatic Control. The first step has been to form a common basis for exchange of subroutines, i.e. a set of programming rules. A considerable amount of effort has been devoted to the task of bringing into the rules all the experience that has accumulated during the years. A general method of adminstrating work areas has been one major objective. See Elmqvist-Tyssø--Wieslander (1976).

Some steps towards the spreading of existing programs to other institutes in the group have been taken. In Denmark, a subset of IDPAC has been implemented, and in Norway work is in progress to evaluate the possibility to implement IDPAC on their NORD-10 computer.

Similarly, the Norwegian program DAREK for linear quadratic synthesis of multivariable systems has been transferred successfully for test purposes to Finland and Sweden.

6. SYSTEM THEORY

The main efforts in this area has been devoted to the analysis and synthesis of multivariable systems by means of algebraic systems theory. Realization theory in its conventional form deals with open loop systems. In Bengtsson (TFRT-3128) the closed loop case is treated. It turns out that conventional realization theory is not directly applicable. It is shown how to convert a "feedforward" compensator into a "feedback" compensator in a way which results in a minimal and stable system. The results imply that there is no significant algebraic difference between a "feedforward" and a "feedback" representation of a control system since the former can easily be transformed to the latter and stability can be guaranteed. This point is important for control synthesis since feedforward compensation on many occasions is much easier to handle. The two representations also provide different information about the feedback system. Essentially, a feedback representation contains information about the sensitivity properties while a feedforward representation contains information about control magnitudes.

Many control problems can be transformed to a mathematical problem of the form

$$M(s)\ X(s) = P(s)$$

where M, X, P are rational matrices and X is to be found so that the equality holds. In control applications M, X, P typically represent the open loop system, the compensator (feedforward representation), and the closed loop system respectively. In Bengtsson and Wonham (TFRT-7107) necessary and sufficient conditions for the existence of a (strictly proper) and stable solution X(s) is given as well as a procedure for its construction. Also, the entire solution set under these restrictions is characterized. In the report, some possible control applications are described.

In Bengtsson (TFRT-3134) the algebraic regulator problem with modelled disturbances is treated in a frequency domain setting. It is shown that an internal model of the environment must be generated in the feedback loop, i.e. in the cascade of plant and compensator, if output regulation shall take place. The concept of internal model is precisely defined. The existence of internal models is established under weaker assumptions than before and the internal model property, as defined, is both necessary and sufficient for output regulation to take place. The internal model property is used to construct a minimal order compensator which creates an internal model of the environment in the feedback loop.

In Bengtsson (TFRT-3131) the general feedforward problem is solved. This report is a revised version of a report published at Dept of Electrical Engineering, University of Toronto.

Lecture notes on algebraic methods in control theory are given in Bengtsson (TFRT-3137), taken from a course given by the author at the Department. A parallel treatment of the basic realization theorems for state space, fraction, and general operator representations of a linear system is given. For state space and fraction representations, the results are more or less standard, while we offer a new proof of the basic realization theorems for general operator representations.

7. APPLICATIONS

7.1 Ship dynamics and control (C Källström)

A new project in collaboration with SSPA (The Swedish State Shipbuilding Experimental Tank) started during the year. A development of the earlier used process identification techniques for determination of ship steering dynamics is planned, and a suitable non-linear ship steering model has been worked out. New experiments have been performed with a 355 000 tdw oil tanker, the Sea Stratus, in collaboration with Kockums Automation AB and Salén Group. Results of determination of linear ship steering models for different types of ships have been published during the year, Åström-Norrbin-Källström-Byström (1975) and Åström-Källström (1976). The program package LISPID for parameter estimation in linear state space models, which has been applied to determine ship steering dynamics among other things, is described in Källström-Essebo-Åström (1976).

The adaptive autopilot for ships, which is described in the last annual report, has been improved in the joint project with Kockums Automation AB. The interactive simulation package SIMNON has been used to test different kinds of autopilots, see Källström (TFRT-3133), and to prepare full-scale experiments. The improved adaptive autopilot, containing a self-tuning regulator for straight course-keeping, a yaw regulator, and a Kalman filter, has been tested on the 355 000 tdw tanker Sea Stratus, owned by the Salén Group. The experiments, which were the last ones in the project, showed that the behaviour of the adaptive autopilot, in all respects, was extremely good.

In Ternrud-Grgic (TFRT-5178) a dynamic model is derived for a submarine rescue vehicle. The model has been simulated using SIMNON. The equation of motion include hydrodynamic forces, propeller forces, and motor equations.

7.2 Wastewater treatment control (G Olsson)

This project is performed in cooperation with Datema AB, Nynäshamn, and the Käppala wastewater treatment plant, Lidingö, Stockholm. The emphasis of the studies has been directed towards the activated sludge process. The activities from previous year have been followed up.

The analysis and simulations of different biological models have continued and the results are summarized in Olsson (TFRT-3129). This analysis has lead to new ideas concerning control methods for dissolved oxygen, when the spatial distribution of the concentrations is taken into account.

The identification experiments have continued at the Käppala wastewater treatment plant. Studies of the settler dynamics have been initiated. The identification results are presented in Olsson-Hansson (TFRT-7094) and in Olsson-Hansson (1976a). The dissolved oxygen loop has been closed at Käppala and experiences are reported in Olsson-Hansson (1976b).

During the year G Olsson has been invited to give two survey papers, one at the Engineering Foundation Conference on Chemical process control at Asilomar, California, see Olsson (1976b) and another paper together with Professor John F Andrews at the Third National Conference on Complete Water Reuse, Cincinnati, Ohio, see Andrews-Olsson (1976).

G Olsson spent the second half of 1975 at the University of Houston, Houston, Texas, as a visiting professor, see Olsson (TFRT-8021). The main research effort during that time was directed towards biological modeling and analysis.

7.3 Climatized buildings (L Jensen)

This project has been reported in earlier activity reports and is supported by the National Board of Building Research (BFR).

A digital quotient regulator was described in last activity report. Computer control experiments of an electrical air--heater have been performed, where the regulator was shown to work satisfactorily.

Experiments have also been made with an on-off valve controlled by a heat actuator. The valve has been tested in continuous operations. The valve position was controlled by fast pulse-length modulation of the power, see TFRT-3095.

The interactive program IDPAC (TFRT-3099) has been expanded in order to allow for particular measurement analysis. The program package (DATPAC) can handle different types of statistical analysis of the data. The data set can be split up into parts if desired and the data values can be limited and tested. A data file can be sorted into given classes. Frequency functions can also be calculated.

Part of the work with DATPAC was performed in an MS-thesis (TFRT-5179). The programs as well as the controllers derived were tested in a process, consisting of an eight-step heat pump. The pump normally recovers heat from the exhaust air and recycles the air into the inlet air. The quotient regulator turned out to be the best one according to the chosen criteria.

Energy measurements were also performed on a building in Malmö and on five buildings with termostatic radiator valves in Landskrona. Laboratory tests were made as well.

The climate has been controlled in an office building in Malmö. The process computer had to be reprogrammed and was later connected to the PDP 15/35 computer at the Department. The PDP 15 is used for data logging and calculation of more complex control algorithms.

A pneumatic actuator has been studied, where pulse-length modulation control was tested for the valve position control. This type of control is preferable because of the price. Ordinary I/P transducers can be avoided. Simple experiments have shown that the local gain changed only by a factor of two. The results are therefore considered to be satisfactory.

7.4 Biomedical problems (P Hagander, J DiStefano)

The microcirculation studies are continued together with the Department of Experimental Medicine at Pharmacia. In Rutili et al (TFRT-3127) a preliminary version is given of a model for the transport of macromolecules across the capillary membrane. Further experiments are now being made.

Preliminary modelling of the oxygen transport in a muscle has been made for the purpose of experimental design. The work in Malmö on the local blood flow control during cancer therapy was moved to Pharmacia, where anatomical studies are combined with extensive experimentation on the kidney in order to determine the necessary relations between the number and diameter of blocking spheres and of capillaries.

An MS-thesis was completed on the pharacokinetics and the pharmacodynamics of an eyepressure drug, Bolanowski (TFRT-5165).

Professor J J DiStefano, III, from UCLA is visiting the Department from January to September 1976. Apart from some work on the identifiability and experimental design for thyroid system he is participating in a group working on the insulin-glucose system. Jan Thorell and K-G Tranberg have done infusions of insulin and glucose also into the portal vein of human subjects, and they have thus access to the role of the liver uptake. Data suggests in most cases a single exponential decay after a pulse input but also a dose dependence of the parameters. Models closer to the physiological reality than a single plasma pool are investigated in order to incorporate the nonlinearity. New experiments are suggested. On the other hand the simpliest possible models are sought for a screening intravenous glucose tolerance test, which might give a diagnosis of prediabetes.

Some work was done together with Clinical Chemical Lab in Lund on the oral glucose tolerance test.

A special meeting on medical applications of control was arranged at the Department on June 10, 1976. Researchers in the field of medicine and automatic control participated from the Lund University Hospital, the Karolinska Institutet, Stockholm, and from the Department. Professor E Biondi from Milano was invited for the meeting. The program is listed in Appendix D.

In Herbertsson-Lundin (TFRT-5162) some identification experiments of the human transfer function are reported. The test persons should track different types of disturbances using a control stich. Different types of dynamics from the control stich input to the output were used in the experiments.

7.5 Microcomputers in control (L Andersson, B Wittenmark)

The program development tools for microcomputers has been further developed. The assembler and linking loader now works for Intel 4004, 4040, 8008, and 8080. They are described in Andersson (TFRT-3098) and Wolgast-Miszczuk (TFRT-5172). Programming of an Intel 3000 is discussed in Hansson-Larsson (TFRT-5164).

Medium level languages called MLP and HILP-80 for the Intel 8008 and 8080 respectively have been defined and compilers implemented using the template macro-processor STAGE II. These languages contain some high level features such as IF-THEN-ELSE-statements and various kinds of loops. They also contain statements at lower levels all the way down to assembly language. They are described in Aspernäs (TFRT-5177).

Microcomputer systems based on Intel 4040 and 8080 have been developed. They contain CPU, memory, A/D and D/A converters. A so called "quotient controller", realizing the expression $u(t) = y_r \cdot u(t-1)/y(t)$ has been implemented on the 4040, see Nilsson (TFRT-5179). A self-tuning regulator as described in Wittenmark (TFRT-3054) has been implemented on the 8080. The regulator can handle 9 parameters, and the implementation is described in Kiziroglu (TFRT-5182).

An attempt to use a microcomputer to replace an analog regulator in a level system on a gun is discussed in Rehnberg (TFRT-5180).

In Sixtensson (TFRT-5183) programs for Intel 8080 are given which will be used to implement different kinds of extremal seeking algorithms. In the thesis a comparison has been done between Intel's PL/M and HILP-80. For the tested programs it turned out that HILP is more efficient with respect to memory requirements.

7.6 Miscellaneous applications

Several applications studies have been performed in MS-works or in smaller project studies made by the staff at the Department.

7.6.1 Pressure regulation

A system for pressure regulation by variation of the recirculation around a pump has been studied, mainly using the simulation program SIMNON. The stability and regulation speed of two different types of on-off controls were examined, and the results are collected in Sternby (TFRT-7095).

7.6.2 State feedback of a boiling water reactor

A simplified controller for a boiling water reactor was developed in an MS-thesis, Holmberg-Svensson (TFRT-5168). The reactor was originally controlled by a linear constant feedback from the estimated states. The estimator was a Kalman filter and the feedback was designed by linear optimal control. In this thesis the given state feedback is approximated by a constant output feedback using a method developed by G Bengtsson. See Bengtsson-Lindahl, Automatica 10 (1974) 15-30. The output feedback is designed so that it preserves the dominant modes of the original closed loop system. The feedback parameters are further tuned by using a combined simulation optimization procedure available in the Simnon program. The resulting output feedback was simulated on a hybrid computer and the result appeared to be satisfactory.

7.6.3 Power systems

A couple of master theses have been made in the area of power systems. The use of computers for supervisory control of high voltage regulation transformer stations was investigated in Börjesson-Martinsson (TFRT-5163). A comparison between a computer and a programable binary logic system is also done.

A study of the general observability problem in power systems is presented in Lübeck (TFRT-5171). Also an algorithm for determination of observability in power systems is given. The presented algorithm determines observable subsystems in power systems by making an investigation of the network topology and the measurement configuration. The work was done at ASEA, Västerås.

Frequency responce measurements of a power plant in Örebro were done by Stal-Laval. The measurements have been analysed in a master thesis, Flato-Hodosi (TFRT-5181). The obtained dynamical model has been simulated and different controllers have been investigated.

7.6.4 Dynamic models of boilers

In cooperation with Kockums AB different subsystems of marine boilers have been investigated. The drum level control system is investigated in Gren (TFRT-5169). Different methods to reduce the disturbance from the rolling of the ship are discussed. The work shows how a feedforward signal from the steam flow can decrease the roll effects and also improve the control of the level of load changes.

In Göransson-Runermark (TFRT-5174) a model of the superheater system is derived. Different methods to control the steam temperature have been investigated through simulations.

7.6.5 Computer load

Different ways to define computerload is discussed in Jonsson (TFRT-5166). Based on the definitions different ways to measure the load on the computer is discussed. A set of programs is derived for MODCOMP, MAX III, which can be used in a real time system to measure the load on the computer. The work was done at ASEA, Västerås.

7.6.6 Airplanes

An emergency pitch control system for an airplane with reduced static stability is discussed in Jansson (TFRT-5170). The thesis was done at SAAB-SCANIA AB in Linköping. The objective of the work was to find the minimum number of sensors necessary for a fixed gain system. Different models and feedback structures were investigated using simulations.

Digital control of the exhaust nozzle of a turbofan engine is discussed in Eliasson (TFRT-5176). The work was done in cooperation with Volvo Flygmotor. The investigation resulted in different digital controllers which will be tested on a large simulation model. The turbofan engine has also been used as an application example to demonstrate different ways to design digital control loops, see Wittenmark (TFRT-3130).

APPENDIX A - LIST OF PERSONNEL

Professor	Karl Johan Åström
University lecturers (Universitetslektorer)	Gustaf Olsson (on leave in the USA Fall 1975) Björn Wittenmark
Docent	Lennart Ljung (Professor at Linköping University from July 1, 1976)
Research assistant (Forskarassistent)	Per Hagander
Research Engineers (Forskningsingenjörer)	Leif Andersson Gunnar Bengtsson (with ASEA since May 1976) Ulf Borisson (with Gränges Data since April 1976) Hilding Elmqvist (half time teaching assistant) Tommy Essebo (programmer) Ivar Gustavsson (on leave in the USA Oct 1975 - April 1976) Torkel Glad (half time teaching assistant) Jan Holst (part time assistant) Lars Jensen (half time) Claes Källström Tomas Schöntahl (programmer) Jan Sternby (half time acting university lecturer) Johan Wieslander

Teaching assistants (Assistenter)	Bo Egardt
	Per Olof Gutman
	Bo Leden (with Norrbottens Järnverk since Nov 1975)
	Matz Lenells
	Sven Erik Mattsson (since May 1976)
	Per Molander
	Lars Pernebo
Laboratory engineer (Lab ingenjör)	Rolf Braun
Visiting scientist (Gästforskare)	Joseph DiStefano III, UCLA, Los Angeles
Technical drawings (Tekniskt biträde)	Britt-Marie Carlsson
Secretaries (Sekreterare)	Eva Dagnegård
	Eva Schildt
Typist (Skrivhjälp)	Gudrun Christensen

APPENDIX B - PUBLISHED PAPERS

Anderson L: Program development for microcomputers using a host computer. MIMI 75, Zürich, June 2-5, 1975.

Andrews J F and Olsson G: A computer based operational strategy for the joint treatment of municipal and industrial wastewaters. The Third National Conference on Complete Water Reuse, Cincinnati, Ohio, USA, June 27-30, 1976. Also report TFRT-7099.

Åström K J: Self-tuning regulators. Paper presented at the NASA/AMES Workshop on Systems Reliability for Future Aircraft, Aug 18-20, 1975. Also report TFRT-3126.

Åström K J: Flow systems. Paper presented at the Conference on Directions in Decentralized Control, Many-person Optimization and Large-scale Systems, Boston, August 1975.

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TFRT-7094 Olsson G and Hansson O: Maximum likelihood identification of the dissolved oxygen dynamics of the Käppala wastewater treatment plant. February 1976.

TFRT-7095 Sternby J: Tryckreglering genom variabel återcirkulation (Pressure control with variable flow recirculation). March 1976.

TFRT-7096 Borisson U: A computer program for simulation of multivariable self-tuning regulators. March 1976.

TFRT-7097 Ljung L: Analysis of recursive, stochastic algorithms. March 1976.

TFRT-7098 Åström K J: Processreglering med datorer. Föredrag vid kemistsamfundets konferens Datorer och Kemi, Gothenburg, Nov 28, 1975. March 1976.

TFRT-7099 Andrews J F and Olsson G: A computer based operational strategy for the joint treatment of municipal and industrial wastewaters. March 1976.

TFRT-7100 Ljung L: On the convergence of certain recursive algorithms. May 1976.

TFRT-7101 Olsson G: Besök vid bilspeditionskoncernen i Göteborg (Visit at the Bilspedition AB, Gothenburg) April 1, 1976. June 1976.

TFRT-7102 Axler E, Berman M, Herbertsson C-G, Jeppsson A, and Tenne O: Simulering av produktionsstyrning i en verkstadsindustri. Projektarbete i Systemteknik (Simulation of production control in a manufacturing industry. Independent project in Systems Engineering). June 1976.

TFRT-7103 Flato J, Olofsson S, Runesson M, Nilsson M, and Påhlsson P: FIVA - Reglering av värmeväxlare på Findus, Bjuv (FIVA - Control of heat exchangers at Findus). June 1976.

TFRT-7104 Sternby J: On consistency for the method of least squares using martingale theory. July 1976.

TFRT-7105 Källström C: Simulering av en analog PID-regulator (Simulation of an analog PID regulator). July 1976.

TFRT-7106 Olsson G and Hansson O: Stochastic modeling and computer control of a full scale wastewater treatment plant. August 1976.

TFRT-7107 Bengtsson G and Wonham W M: On causal and stable solutions to rational matrix equations with application to control theory. July 1976.

Travel reports

TFRT-8019 Ljung L: Rapport från en resa till USA (Report from a travel to USA) Oct 8, 1974 - Oct 9, 1975. November 1975.

TFRT-8020 Gustavsson I: Reserapport från USA (Traveling report from USA) Oct 1, 1975 - April 15, 1976. June 1976.

TFRT-8021 Olsson G: Rapport från en resa till USA (Report from a travel to the USA) June 24, 1975 - January 24, 1976. July 1976.

APPENDIX D - GRADUATE COURSES AND SEMINARS

The graduate courses and other seminars given at the Department during the academic year are summarized here. The courses are given by the staff of the Department, invited lecturers or in cooperation with other Departments of the Institute.

PhD Courses

Linear Estimation (L Ljung)

ABC of Identification and Adaptive Systems (L Ljung, K J Åström, B Wittenmark, U Borisson, C Källström)

Algebraic Methods for Linear Systems (G Bengtsson)

Optimization Methods (T Glad)

Linear Quadratic Control Theory (L Ljung)

System Theory (P Hagander, G Bengtsson, L Ljung)

Stochastic Control Theory (P Hagander)

Model Building Techniques (K J Åström, P Hagander)

Model Reference Adaptive Systems (I D Landau, Univ of Grenoble, France)

Seminars

Dr P E Wellstead, University of Manchester (UMIST), England,
"Basic Ideas in Bond Graph Techniques", Aug 15, 1975,
"Power Flow and Causability", Aug 18, 1975,
"Applications of Bond Graph Techniques", Aug 19 and 20, 1975,
"A Nonparametric Selfadjusting System for Earthquake simulation", Sept 11, 1975.

Mr U Borisson, Lund Institute of Technology.
"Flervariabla självinställare" ("Multivariable Self-tuning Regulators"), Sept 12, Sept 16, and Sept 19, 1975.

Dr H Kimura, Dept of Control Engineering, Osaka University, Japan. "Partial Observers, A Geometric Approach", Sept 18, 1975.

Mr T Glad, Lund Institute of Technology.
"Optimering under bivillkor" ("Constrained Optimization"), Sept 23, Sept 25, and Sept 30, 1975.

Dr C H Wells, Measurex Inc, Cupertino, Calif, USA.
"Minimal Energy Control of Batch Digerters and Adaptive Modelling for Control", Oct 1, 1975.

Discussion on Adaptive Control with participants from Lund Institute of Technology and Kockums Mekaniska Verkstads AB, Oct 2, 1975.

Mr J Sternby, Lund Institute of Technology.
"Tryckreglering" ("Pressure Control"), Oct 14, 1975.

Mr R Syding, LKAB, Kiruna.
"Processtyrning i gruvindustrin" ("Process Control in the Mining Industry"), Oct 20, 1975.

Dr L Ljung, Lund Institute of Technology.
"Identifiering och konsistens" ("Identification and Consistency"), Oct 28, 1975.
"Rekursiva stokastiska algoritmer" ("Recursive Stochastic Algorithms"), Nov 4, 1975.

Mr L Johnsson, ASEA, Västerås.
"Reglerproblem i kraftindustrin" ("Control Problems in the Power Industry"), Nov 7, 1975.

Prof K G Andersson, Dept of Mathematics, Lund University.
"Katastrofteori, en översikt" ("Catastrophy Theory, a survey")
Nov 13, 1975.

Dr G Bengtsson, Lund Institute of Technology.
"Realization of Feedback Systems", Nov 20, 1975.
"Dynamic Assignment and Regulator Problems in Linear Multivariable Systems", Nov 27, 1975.

Dr René Boel, U C Berkeley, Calif, USA.
"Discrete Time Martingales in Dynamic Programming", Dec 19, 1975.

Dr Olav Aarna, Talinn Polytechnical Institute.
"Modelling", Jan 23, 1976.

Dr J J DiStefano, III, UCLA, Los Angeles, Calif, USA.
"Hierarchial Models and Identification Problems in some Physiologic Systems", Jan 30, 1976.

Mr J Wieslander, Lund Institute of Technology.
"Stage 2", April 14, 1976.

Mr L Andersson, Lund Institute of Technology.
"Intel 8080 and Hilp 80", April 14, 1976.

Prof I D Landau, Institut National de Polytechnique de Grenoble, France. "Model Reference Adaptive Techniques", April 26, 27, 28, 29, and 30, 1976.

Prof V Strejc, Institute of Information Theory and Automation, Prague, Czechoslovakia.
"A Probabilistic Approach to Adaptive Control", April 28, 1976.
"Solution of Riccati Equations by Choleski Decomposition", May 3, 1976.
"Stability of Multivariable Systems", May 4, 1976.

Dr J J DiStefano, III, UCLA, Los Angeles, Calif, USA.
"T_4 to T_3 Conversion in Different Tissues; Biological Experiment Design by Identifiability Analysis", May 6, 1976.

Mr G Andersson, Ångpanneföreningen, Malmö.
"Praktiska reglerproblem i kraftindustrin" ("Practical Problems in the Power Industry"), May 12, 1976.

Prof A Spang, General Electric Company, USA.
"Distributed Computer Systems for Control", May 18, 1976.
"Data Ports", May 20, 1976.
"Failure Detection and Connection in Jet Engines", May 21, 1976.

Prof E Jury, Univ of California, Berkeley, Calif, USA.
"Results on the Theory and Application of Inners", May 21, 1976.

Dr D Watanapongse, Inland Steel Company, USA.
"Application of Modern Control Techniques to Computerized Setup of Effective Operation of Inland Strip Mills", May 24, 1976.

Prof C DonCarli, University de Nantes, France.
"Recursive Identification and Adaptive Systems", June 3, 1976.

Prof A Segall, MIT, Cambridge, Mass, USA.
"Estimation and Control Methods in the Analysis of Communication Networks", June 18, 1976.

Prof L M Silverman, University of Southern California, Los Angeles, Calif, USA.
"Relative Primeness of Polynomial Matrices", June 24, 1976.

Dr M Davies, Imperial College, England.
"Jump Processes and Related Control Problems", July 1, 1976.

<u>Interactive Computation of Dynamical Systems</u>. Course for industrial and university people given at the Department, June 1-2, 1976.

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"), I Gustavsson.

4. "Industriella tillämpningar av IDPAC" ("Industrial Applications of IDPAC"):

   "Båtdynamik" ("Ship Dynamics"), K J Åström, C Källström

   "Reningsverk" ("Wastewater Treatment Plants"), G Olsson

5. "SIMNON - ett interaktivt simuleringsprogram för olinjära system" ("SIMNON - An Interactive Simulation Program for Non-linear Systems"), H Elmqvist.

6. "Tillämpningar av SIMNON" ("Applications of SIMNON"):

   "Simulering av dynamiska förlopp i en kraftstation" ("Simulation of the Dynamics of a Hydro-Power Plant"), S Lindahl, Swedish State Power Board, Stockholm.

   "Simulering av styrsystem för supertankers" ("Simulation of Ship Steering Systems"), C Källström.

   "Farmakokinetik" ("Farmacokinetics"), K J Åström, G Wettrell (Lund University Hospital).

7. "Datorstödd syntes av reglersystem" ("Computer Aided Design of Control Systems"), L Pernebo.

8. "Simulering av reglersystem för en avgaspanna" ("Simulation of the Control System of an Exhaust Gas Boiler"), G Andersson, Ångpanneföreningen, Malmö.

9. "SYNPAC - ett interaktivt programsystem för syntes av reglersystem" ("SYNPAC - An Interactive Program System for the Synthesis of Control Systems"), J Wieslander.

10. "Dimensionering av styrautomater för flygplan med linjär-kvadratisk teori och SYNPAC" ("Synthesis of Autopilots for Aircrafts with Linear Quadratic Theory and with SYNPAC"), P O Elgcrona, SAAB-Scania, Linköping.

11. "Kombination av simulering och optimering för syntes-ändamål" ("A Combination of Simulation and Optimization for Control Design Purposes"), T Glad.

12. "DAREK - Interaktivt programsystem för konstruktion av flervariabla reglersystem" ("DAREK - An Interactive Program System for the Design of Multivariable Control Systems"), A Tyssø, Dept of Engineering Cybernetics, Norwegian Institute of Technology, Trondheim, Norway.

13. "Implementering av interaktiva program" ("Implementation of Interactive Programs"), J Wieslander.

Meeting of the Heads of Control Laboratories in Europe, June 8-9, 1976.
This meeting takes place once each year at different control departments in Europe. Areas of common interest were discussed during the meeting such as graduate and undergraduate coursework, laboratory equipment and laboratory exercises in control education. The following lectures were given at the meeting:

"Engineering Education in Sweden", B Wittenmark (Lund Institute of Technology).

"Control Research in Sweden", G Olsson (Lund Institute of Technology).

"Bioengineering Problems Related to the Acoustical System", E Biondi (Politechnica di Milano, Italy).

Symposium on Medical Applications of Control, June 10, 1976.
Lectures presented:

Prof E Biondi, Milano.
"Bioengineering Problems Related to the Accoustical System", "Presentation of the Activities at the Milano Laboratory on the Vestibularis System, Locomotion, Scoliosis etc."

Doc E Borg, Karolinska Institutet, Stockholm.
"Control of the Sound in the Middle Ear".

Dr P Hagander, Lund Institute of Technology.
"Presentation of the Bioengineering Activity at the Department of Automatic Control, Lund".

Doc N G Henriksson, Lund University Hospital.
"Discussion of a Project on Nystagmus".

APPENDIX E - LECTURES BY THE STAFF

1975

June 27 G Olsson: Identification of Nuclear Reactor Dynamics. Systems Control Inc, Palo Alto, Calif, USA.

Aug 7 L Ljung: Fast Algorithms for Estimation. Stanford University Electronics Research Review, Stanford University, Calif, USA.

Aug 26 L Ljung: On the Accuracy Problem in Identification. 6th IFAC World Congress, Boston, Mass, USA.

Aug 19 K J Åström: Self-Tuning Regulators. MIT NASA/AMES Workshop on Systems Reliability for Future Air-crafts. MIT Cambridge, Mass, USA.

Aug 27 K J Åström: Theory and Applications of Adaptive Regulators Based on Recursive Parameter Estimation. 6th IFAC World Congress, Cambridge, Mass, USA.

Sept 2 G Olsson: Some Modeling Problems in Biological Waste Treatment. Environmental Systems Engineering Dept, Clemson Univ, Clemson, S C, USA.

Sept 2 L Ljung: Asymptotic Analysis of Recursive, Stochastic Algorithms. Yale University, New Haven, Connecticut.

Sept 5 K J Åström: Stochastic Adaptive Control. University of Connecticut, Stores, Connecticut, USA.

Sept 7 K J Åström: Research in Automatic Control at Lund Institute of Technology. Foxboro, Mass, USA.

Sept 8 L Ljung: An Overview of System Identification and Adaptive Control. Statistical Science Center, Univ of New York at Buffalo, Buffalo, N Y, USA.

Sept 9	L Ljung: Scattering Theory and Linear Estimation. Univ of Toronto, Toronto, Ontario, Canada.
Sept 11	L Ljung: Advances in System Identification. Univ of Toronto, Toronto, Ontario, Canada.
Sept 15 - 19	H Elmqvist: Demonstration of SIMNON at the exhibition "Datakraft -75", Mässhallarna, Malmö, Sweden.
Sept 18	L Ljung: Identification of Systems with Feedback. Princeton University, Princeton, N J, USA.
Sept 25	L Ljung: Convergence of Recursive, Stochastic Algorithms. Brown University, Providence, R I, USA.
Oct 1	G Olsson: Control Problems in Wastewater Treatment. Depts of Civil and Chemical Engineering, Dept of Statistics, Univ of Wisconsin, Madison, Wisconsin, USA.
Oct 2	Contact meeting at Kockums, Malmö, Sweden, "Methods for Adaptive Control": C Källström: Prov med adaptiv styrning (Tests of Adaptive Control), C Källström: Andra typer av adaptiv styrning för fartyg (Alternative Adaptive Ship Steering Control Systems), K J Åström: Varför behövs adaptiva autopiloter? (Why Adaptive Control for Ship Steering?), K J Åström: Jämförelse med autopiloter för flygplan (A Comparison with Autopilots for Aircrafts).
Oct 2	L Ljung: Convergence of Recursive, Stochastic Algorithms. Mass. Institute of Technology, Cambridge, Mass, USA.

Oct 3	L Ljung: Convergence of Recursive, Stochastic Algorithms. Harvard University, Cambridge, Mass, USA.
Oct 5	L Ljung: Identification of Systems with Feedback. Harvard University, Cambridge, Mass, USA.
Oct 9	T Glad: The Extension of the Hestenes-Powell Method to Optimal Control Problems. Dept of Applied Mathematics, Linköping University, Sweden.
Oct 16	G Olsson: Experiences of On-line Computers in Wastewater Treatment Plants. Water Department, City of Philadelphia, Penn, USA.
Oct 30	G Olsson: Computer Control of a Wastewater Treatment Plant. Univ of Houston and Rice Univ, Houston, Texas, USA.
Oct 20 - Dec 1	I Gustavsson: Identification and Self-Tuning Regulators (a seminar series with 13 seminars). MIT, Cambridge, Mass, USA.
Nov 7	L Pernebo: Discrete System Representation Using the Inverse Operator. Control Systems Centre, UMIST, Manchester, UK.
Nov 14	G Olsson: Computer Control of a Wastewater Treatment Plant. Depts of Civil and Chemical Engineering, Univ of Texas at Austin, Texas, USA.
Nov 28	B Wittenmark: Self-Tuning Algorithms for Control, Prediction, and Smoothing. Imperial College, London, UK.
Nov 28	K J Åström: Processreglering med dator (Computerized Process Control). Svenska Kemistsamfundets konferens Datorer och Kemi, Göteborg, Sweden.

Dec 3 I Gustavsson: Recursive Identification Methods. McMaster University, Hamilton, Canada.

Dec 4 L Pernebo: An Equivalence Relation for Discrete Time Systems. Control Engineering Group, Univ of Cambridge, Mass, USA.

Dec 5 I Gustavsson: Recursive Identification Methods. Univ of Toronto, Canada.

Dec 5 I Gustavsson: Identification of Closed Loop Systems. Univ of Toronto, Canada.

Dec 8 H Elmqvist: SIMNON - Ett interaktivt simuleringsprogram för olinjära system (SIMNON - An Interactive Simulation Program for Nonlinear Systems). Stockholm Computer Centre, QZ, Stockholm, Sweden.

Dec 15 I Gustavsson: Identification of Closed Loop Systems. Brown University, Providence, R I, USA.

1976

Jan 15 K J Åström: Adaptive Control. Honeywell, Minneapolis, USA.

Jan 15 K J Åström: Recent Progress in the Theory of Self-Tuning Regulators. Univ of Minnesota, Twin Cities, St Paul, Minnesota, USA.

Jan 15 G Olsson: Identification and Control of Wastewater Treatment Plants. Dept of Chemical Engineering, Univ of Alberta, Edmonton, Alberta, Canada.

Jan 19 G Olsson: State of the Art in Sewage Treatment Plant Control. Survey paper, Engineering Foundation conference on Chemical Process Control, Asilomar, Pacific Grove, Calif, USA.

Jan 20	K J Åström: State of the Art and Needs in Process Identification. Invited review paper, Engineering Foundation conference on Chemical Process Control, Asilomar, Pacific Grove, Calif, USA.
Jan 27	I Gustavsson: Identification of Closed Loop Systems. Harvard University, Cambridge, Mass, USA.
Febr 6	T Glad: Ein wechselwirkendes Optimierungsprogram für dynamische Systeme. Technische Universität, Dresden, DDR.
March 8	I Gustavsson: Recursive Identification and an Interactive Identification Program Package. Stanford University, Stanford, Calif, USA.
March 17	L Ljung: Adaptive Control - Examples and Problems. Uppsala University, Uppsala, Sweden.
March 18	L Ljung: Linear Estimation. Uppsala University, Uppsala, Sweden.
March 19	L Ljung: Convergence of Recursive, Stochastic Algorithms. Dept of Optimization Theory, Royal Institute of Technology, Stockholm, Sweden.
March 25	I Gustavsson: Recursive Identification Techniques. USC, Los Angeles, Calif, USA.
March 26	I Gustavsson: Recursive Identification Methods. UCLA, Los Angeles, Calif, USA.
March 26	I Gustavsson: Closed Loop Identification. UCLA, Los Angeles, Calif, USA.
April 1	I Gustavsson: Practical Identification Problems and an Interactive Program Package for Identification. USC, Los Angeles, Calif, USA.

April 1	G Olsson: Användning av reglertekniska metoder i transportproblem (Control Methods in Transport Systems). Bilspedition AB, Göteborg, Sweden.
April 6	G Olsson: Mät- och instrumenteringsproblem i reglering av reningsverk (Instrumentation Problems in Wastewater Treatment Control). Royal Institute of Technology, Institute of Environmental Studies, Stockholm, Sweden.
April 23	K J Åström: Systemaspekten på mätteknik (Measurement Problems from the Systems Point of View). IVA Symposium "Nya Mätmetoder - Nya Mätproblem", Stockholm, Sweden.
May 18	I Gustavsson: Processidentifiering (System Identification). SCA, Sundsvall, Sweden.
May 24	G Olsson: Mät- och reglersystem i reningsverk (Instrumentation and Control Systems in Wastewater Treatment Plants). Dept of Physics and Measurement Technology, Linköping Institute of Technology, Linköping, Sweden.
June 1-2	Interactive Computation of Dynamical Systems. Course for industrial and university people (see Appendix D).
June 8-9	Meeting of the Heads of Control Laboratories in Europe. See Appendix D.
June 10	Symposium on Medical Applications of Control. See Appendix D.
June 15	K J Åström: Modern and Classical Control - A Rapprochement. Honeywell, Minneapolis, USA.

June 18 K J Åström: Stochastic Control and Self-Tuning Regulators. NASA Langley Research Center, Langley Field, Virginia, USA.

June 23 L Ljung: Fast Algorithms for Recursive Identification. IEEE Information Theory Symposium, Ronneby, Sweden.

June 23 P Hagander: A Self-Tuning Filter for Fixed-Lag Smoothing. IEEE Information Theory Symposium, Ronneby, Sweden.

June 24 L Ljung: Asymptotic Detection in Finite Model Families. IEEE Information Theory Symposium, Ronneby, Sweden.

APPENDIX F - TRAVELS

K J Åström participated in the 6th IFAC World Congress in Boston, in MIT NASA/AMES Workshop on systems reliability issues for future aircrafts, and in the conference on Directions in Decentralized Control, Many Person Optimization and Large-Scale Systems. In connection with the trip to Boston he also visited the MIT, Harvard, University of Connecticut and Foxboro. In November he participated in the conference Computers and Chemistry (Datorer och Kemi) in Gothenburg. In January he participated in the Engineering Foundation Conference on Chemical Process Control. Asilomar Calif, En route he also visited University of Minnesota and Honeywell to learn about their adaptive flight control systems. In April he participated in the IVA symposium on New measuring techniques - New measurement problems (Nya mätmetoder - nya mätproblem) in Stockholm. In June Åström visited Honeywell and NASA, Langley.

G Bengtsson was on leave of absence at the University of Toronto, Toronto, Canada, until the beginning of October 1975. He participated in the 6th IFAC World Congress, Boston, Mass, Aug 25-30, 1975.

H Elmqvist attended a seminar on Automatic Formula Manipulation held by A Hearn, University of Utah, at Stockholm Computer Centre, April 22, 1976. He also participated in a meeting between ITM (Swedish Institute of Applied Mathematics) and the Swedish State Power Board held in Stockholm June 11, 1976. A seminar about SIMNON was then given.

T Glad attended the 9. Fachkolloqium Informationstechnik in Dresden, DDR, Feb 4-5, 1976. He presented a paper.

I Gustavsson has been on leave from the Department from October 1975 to April 1976. During the period October - December 1975 he visited Massachusetts Institute of Technology, Cambridge, Mass, USA, and after that Harvard University, Cambridge, Mass, Stanford University, Stanford, California, and University of Southern California, Los Angeles, Calif, one month at each of them. This is reported in Gustavsson (TFRT-8020).

C Källström participated in the 4th ship control systems symposium in the Hague, the Netherlands, Oct 27-31, 1975. He also travelled with the tanker Sea Stratus from Lisbon, Portugal, to Cape Town, South Africa, April 12 - May 3, 1976. During the travel experiments with the adaptive autopilot were tried out.

L Ljung was with the Information Systems Laboratory, Stanford University, California, until mid August 1975. He participated in the 6th IFAC World Congress in Boston, Mass, in August 1975 and visited a number of North American universities in September - October 1975. This travelling is reported in Ljung, TFRT-8019. In June 1976 he participated in the IEEE Information Theory Symposium in Ronneby, Sweden.

G Olsson was on leave from the Department during the second half of 1975 and stayed as a visiting professor at the Univ of Houston, Houston, Texas, USA. During that time he participated in the 6th IFAC World Congress, Boston, Mass, August 1975, the Water Pollution Control Federation 48th Annual Meeting, Miami Beach, Florida, October 1975, the IEEE Conference on Decision and Control, Houston, Texas, December 1975, and the Engineering Foundation Conference on Chemical Process Control, Pacific Grove, California, January 1976. He also visited a number of university departments and research institutes in the USA and Canada. It is reported in a travel report, TFRT-8021.

<u>L Pernebo</u> visited the Control Systems Centre at UMIST, Manchester, during Sept 22 to Nov 22, 1975, The Control Engineering Group at University of Cambridge, Cambridge, from Nov 22 to Dec 6, 1975, and the Department of Computing and Control at Imperial College, London, from Dec 6 to Dec 11, 1975.

<u>B Wittenmark</u> visited Oxford University and Imperial College November 27-28, 1975. During the spring 1976 he participated in a four-week course for studierektorer (Directors of Studies) held by UKÄ. In June 16-20, 1976, he participated in the IFAC Symposium on Large Scale Systems in Udine, Italy, where he also participated in the meeting of the International Program Committee for the IFAC Symposium on Trends in Automatic Control Education to be held in Barcelona in 1977.