Activity Report 1996-97

Helbo, Jan; Madsen, G.L.

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Aalborg University

DEPARTMENT OF CONTROL ENGINEERING

Activity Report 1996-97

Visiting address: Institute of Electronic Systems
Department of Control Engineering
Fredrik Bajers Vej 7C
9220 Aalborg Øst

Phone: +45 96 35 87 00
Fax : +45 98 15 17 39
E-mail: sekr@control.auc.dk
www: http://www.control.auc.dk

The report is edited by: Jan Helbo and Gitte Lynggaard Madsen

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Inaugurated in 1974, Aalborg University now has almost 11,000 students. Teaching and research are conducted at the highest level in the fields of engineering, natural sciences, social sciences and humanities.
The University's annual budget is in excess of 750 million Danish kroner.

PREFACE

This report is the third Activity Report from the Department of Control Engineering. For the past two years the effort has been concentrated on the well-established programs and projects. Besides, the Department has been going through a research evaluation that has affected the organisation of the Department, and focus has also been on the development of a new strategic plan for the Department of Control Engineering.

In this period a new full professor, Jakob Stoustrup, has been appointed in the area of Robust Control

During the period the education has changed and new teaching activities have been initiated. The number of both foreign professors and foreign students visiting the department have increased; mainly because of the participation in the COSY Theme 2 – Network and ERASMUS program but also because of many other contacts to universities abroad.

The organisational structure of Aalborg University is as follows. The university consists of three faculties: Faculty of Social Science, Faculty of Humanities and Faculty of Engineering and Science

The Faculty of Engineering and Science is divided up into a number of institutes of which Institute of Electronic Systems is one. This institute is, furthermore, divided up into five departments: Department of Control Engineering, Department of Medical Informatics and Image Analysis, Department of Communication Technology, Department of Mathematics and Department of Computer Science.

This report is addressed to researchers with interests similar to those of the Department of Control Engineering, to public authorities, and to present and future students interested in control engineering.

Should anything in the following be of special interest or do you have ideas or problems within the area of control engineering do not hesitate to contact the Department. See front page for phone, fax and e-mail.

CONTENTS

1. RESEARCH ORGANISATION

The scope of the department's activities is control engineering, which includes all aspects of automation in relation to industrial processes and production plants. Processes, in this context, should be interpreted widely, as they include thermal as well as electro-mechanical processes. The area spans such tasks as decentralised PLC-controls and single-circuit regulations to master-control systems for large industrial processes.

In the end of 1996 an international evaluation committee evaluated the research activities in the Department. The evaluation was based on a report prepared by the Department of Control Engineering and covered the period 1990-1995. Members of staff made presentations and a session was held in Aalborg. The committee also inspected samples of publications and Ph.D. theses to make a full assessment of the Department.

The committee fully agreed that the Department focuses on automation, which besides traditional control engineering with control loops also include multidisciplinary aspects with complex systems combining mechanical, electronic and software engineering. In this broad area Information Technology (IT) plays an important role and IT is integrated in most of the projects carried out in the department.

On the basis of the research evaluation the Department worked out a strategic plan that is clearer and with a longer time-horizon. These plans are now worked out with a clearer profile and with more focus on project subjects.

General control engineering includes:

- Feed back control of electro-mechanical objects (servo systems) or industrial processes
- Open-loop process control of continuous processes as well as batch processes. Also automatic planning and control of a production sequence according to given specifications
- Supervision, incl. automatic system monitoring
- Operator communication and computer based communication systems, incl. man-machine interface

- Safeguards, incl. alarm systems, fault detection, and fault diagnosis
- Distributed computer- and data systems and networks
- Real-time systems

The application of computers in process control implies a number of traditionally separated disciplines, the integration of which is a main feature of the Department's activities.

These activities are partly based on specific technical control problems, partly on new theories and methods, in which the applications are regarded as exemplifications. Among others, large industrial processes are investigated in relation to power stations, heating and ventilation automatic control (HVAC), where new theories of multi-variable and nonlinear systems are tested.

The Department is engaged in development and design of open sensor-based systems, in which advanced regulation and control strategies can be implemented in connection with co-operating robots. To increase reliability and durability in industrial process control systems, the Department carries out research in the development of systematic methods, both on superior control systems, distributed systems, and at an algorithmic level.

The determination of parameters for new nonlinear loudspeaker models is an example of the application of advanced digital signal processing and system identification.

Apart from solving specific problems, the purpose of the research is to extend the knowledge of new theories and methods. The work also involves development of new theories and methods. For example, the promising area within neural networks has proven to be very suitable for system identification, simulation and regulation.

In order to master all professional fields within control engineering the research in the Department of Control Engineering is organised in four main research areas:

1. Control Theory
2. Modelling and Estimation
3. Fault-tolerant control systems
4. Distributed Real-time systems

1.1 Control Theory

Analysis and synthesis of feedback mechanisms in dynamic systems are the main subjects. The field is in essence interdisciplinary since on one hand it treats dynamic systems as abstract mathematical models that are related to any specific technology, and on the other hand it has applications in practically any industrial sector.

The main research areas of the research group are:

- Self tuning and adaptive control
- Control of nonlinear systems
- Robust and optimal control
- Control of large scale systems
- Neural net for control
- Control engineering for new applications

1.2 Modelling and Estimation

Modelling is a major part in the process of designing a control system. The Department wants to accumulate expertise in this area to derive nominal models and possible uncertainty models for the process. At the same time it is often required to estimate states if no or very noisy measurements are available.

The main research areas cover:

- Grey Box Modelling
- System Identification
- State estimation
- Neural net for system identification

1.3 Fault-tolerant Control Systems

Fault tolerance in control is the ability to cope with faults in components of a controlled plant, and ensure that faults do not develop into failure or emergencies. With an ever-increasing complexity in automation, the vulnerability to faults has become quite high, and experience has shown an increasing demand for better plant availability.

The area of Fault tolerant control deals with:

- Methods for fault detection in industrial processes
- Methods for systematic design of fault tolerant control systems and components
- Software tools for support of design
- Analysis of discrete event systems for support of design of supervisory control
- Industrial tests of results to achieve experience for research and teaching activities
- Fail-safe systems with hardware redundancy

1.4 Distributed Real-time Control Systems

Control systems are viewed as the total control of objects, low-level controllers, interconnecting network, supervisory controllers and Human Computing Interface (HCI).

Controller design relies heavily on a well-defined behaviour of the underlying infrastructure, which is frequently taken for granted. However, since independently designed controllers exist in an environment of shared resources, independence is no longer obvious.

Major issues within this area therefore include:

- Methods for analysing temporal co-existence of task on multiprogramming platforms.
- Capacity analysis of communication networks in control systems.
- Distributions as a mean in fail resilient systems.
- Real-Time information exchange in distributed systems.
- Object Oriented analysis, design and implementation of control systems.

2. STAFF AND Ph.D. STUDENTS

Staff and Ph.D. students by December 1997

Palle Andersen

Born March 31, 1951
BScEE 1974. Ph.D. degree in 1977
Associate Professor since 1991
Research interests: Robust and optimal control. Estimation of model uncertainty.

Thomas Bak, Ph.D. Student/research assistant

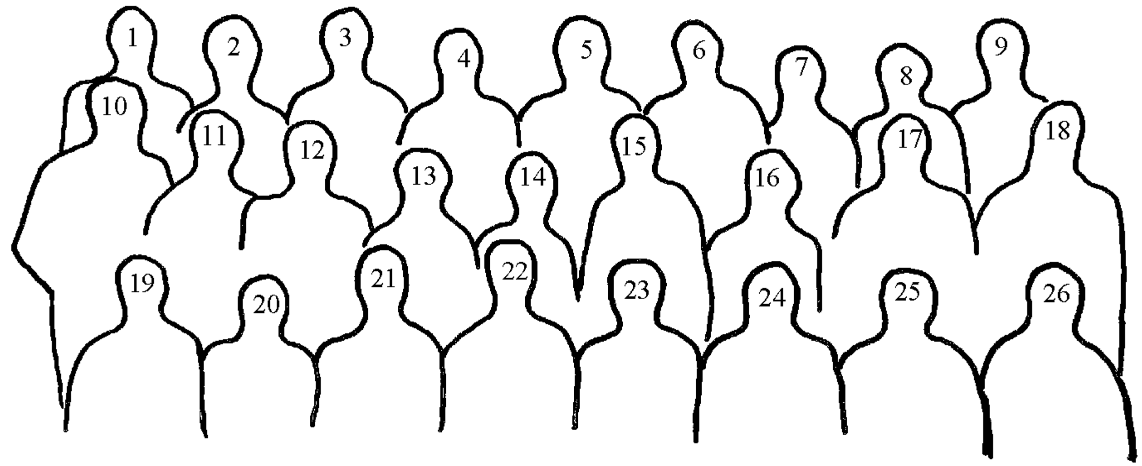
Born December 22, 1967
MScEE 1993
Research interests: Estimation and identification. Satellite attitude determination.

Jan Dimon Bendtsen, Ph.D Student

Born May 24, 1972
MScEE 1996
Research interests: Neural networks used in Control Engineering and modeling. Nonlinear control systems. Stability of nonlinear systems.

Mogens Blanke

Born October 6, 1947
MScEE 1974. Ph.D. degree in 1982
Associate Professor in 1981. Professor since 1990
Research interests: System identification for continuous, non-linear systems and its application to modelling and control of marine systems. Analysis and optimisation of ship propulsion losses. Automatic steering and rudder roll damping for ships. Range of methods applied span from conventional, optimal designs to robust H**.** to adaptive control. Control systems for ship propulsion, including diesel engine controls, thrust, speed and optimal path control. Plant wide integrated control and surveillance systems, with particular emphasis on marine manoeuvring control. Design methods for fault tolerant control systems. This includes component-based analysis of fault propagation, design of fault



1. Mogens Blanke
2. Henrik Schiøler
3. Niels Nørgaard Nielsen
4. Ole Sørensen
5. Bakir Rokic
6. Morten Knudsen
7. Aage Nielsson
8. Ole Jørgensen
9. Per Brath
10. Peter L. Petersen
11. Per Printz Madsen
12. Jakob Stoustrup
13. Jette Damkjær
14. Kirsten M. Nielsen
15. Jan Dimon Bendtsen
16. Henrik Rasmussen
17. Palle Andersen
18. Tako Freerk Lootsma
19. Roozbeh Izadi-Zamanabadi
20. Gitte L. Madsen
21. Søren A. Bøgh
22. Klaus Trangbæk
23. Brian Kirkegaard
24. Tom S. Pedersen
25. Jan Helbo
26. Norddin ElGhouti

handling and autonomous supervision. Fault detection and isolation for industrial systems. Robust control with specific interests in uncertainty modelling and applications.

International research commitments:

- Associate editor for applications for Journal of Robust and Nonlinear Control (Wiley).
- Member of editorial boards for Journal of Marine Science and Technology (Springer) and Brodogradnja (Croatia).
- Chairman of IFAC Co-ordination Committee for Transportation and Vehicles. Chair of Technical committee on Marine Systems until 1996.
- IPC member of major IFAC conferences, e.g., SAFEPROCESS, SYSID, CAMS, and MCMC.
- Reviewer for IEEE Trans. AC, Automatica, IEEE trans. Control Sys. Technology, Control Eng. Practice and others.

Ole Borch

Born April 27, 1943
Associate professor since 1975
Research interests: Object Oriented System Development, Java programming, Computer Networks, Distributed Systems, Information Technology, Microcomputer Systems.

Per Brath, Ph.D. Student

Born May 12, 1964
MscEE 1993
Research interests: Autotuning, Adaptive Control, Supervisory Control, Fault detection and System Identification. Control of HVAC systems.

Søren Abildsten Bøgh, Ph.D. Student/Research Assistant

Born December 5, 1965
MScEE 1991
Research interests: Fault handling in control systems. Satellite attitude control.

Norddin ElGhouti, Ph.D. Student
Born June 10, 1966
MscEE 1997
Research interests: Non-linear Control of Piezo-Electric-Motors

Mads E. Hangstrup, Ph.D. Student
Born May 7, 1971
MScEE 1995
Research interests: Multivariable control system architectures

Mikkel Hede, Ph.D. Student
Born May 10, 1970
MScCE 1994
Research interests: Real-time systems. Distributed systems.

Jan Helbo
Born April 9, 1943
MScEE 1972
Associate Professor since 1976. Head of Department since 1993.
Research interests: Control development systems for robots. Flexible robots. Time optimal trajectory planning and control. Sensor integration. Piezo electric motors.

Roozbeh Izadi-Zamanabadi, Ph.D. Student
Born March 20, 1963
MScEE 1994
Research interests: Fault handling. Supervisory control.

Lars Peter Jensen
Born October 22, 1956
MScEE 1980
Associate Professor since 1989
Research interests: Process control. Man-machine interface for monitoring/control room jobs considering a good working environment.

Niels Jørgensen,

Born August 10, 1954
MScEE 1979
Associate Professor since 1989
Research interests: Realtime distibuted systems. Realtime networking.

Morten Knudsen

Born September 14, 1938
MScEE 1963. Ph.D. degree in 1993
Associate Professor in 1971. Reading Professor since 1990
Research interests: Experimental modelling and parameter estimation, Technology based learning.

Torben Knudsen

Born August 20, 1958
MScEE 1983. Ph.D. degree in 1990
Associate Professor since 1991
Research interests: System identification. Control of wind turbines.

Tako Freerk Lootsma, Ph.D. Student

Born January 21, 1973
MScEE 1997
Research interests: Fault detection and isolation for non-linear systems.

Per Printz Madsen

Born April 12, 1960
MScEE 1985. Ph.D. degree in 1993
Associate Professor since 1994
Research interests: Neural network. Fuzzy logic. Distributed systems.

Jan Henrik Mortensen, Ph.D. Student

Born 23. November 1968
MScEE: 1993
Research interests: Power plant control, Multivariable control, System Identification.

Jens Dalsgaard Nielsen

Born March 8, 1959
MScEE 1983. Ph.D. degree in 1992
Associate Professor since 1992
Research interests: Real-time systems. Distributed systems. Fault-tolerant systems. Hard real-time communication.

Kirsten Mølgaard Nielsen

Born July 19, 1959
MScEE 1984. Ph.D. degree in 1992
Associate Professor since 1992
Research interest: Large scale control systems.

John Nørgaard Nielsen

Born February 2, 1937
MScEE 1961. Ph.D. degree in 1963
Associate Professor since 1974
Research interests: Nonlinear systems, Computer Aided Learning.

Michael Collin Nielsen, Research Assistant

Born July 29, 1971
MScEE 1997
Research interests: Real-time systems. Distributed systems. Hard real-time communication

Tom Søndergaard Pedersen

Born October 22, 1954
MScEE 1980
Associate Professor since 1988
Research interests: Power plant control. Physical modelling.

Henrik Rasmussen

Born November 16, 1944
MScEE 1970. Ph.D. degree in 1996
Associate Professor since 1974
Research interests: Adaptive Control. Induction Motors.

Henrik Schiøler,

Born December 19, 1965
MScEE 1989. Ph.D. degree in 1993
Assistant Professor since 1993
Research interests: Real-time systems, traffic analysis, scheduling theory, probability theory, queuing theory, real-time communications networks.

Jakob Stoustrup,

Born January 16, 1963
MScEE 1987. Ph.D. degree in 1991
Associate Professor since 1995, Professor since 1997
Research Interests: H-infinity control theory; Mu control theory; L-1 control theory; Optimisation based control; Loop Transfer Recovery Methods; Uncertainty modelling; Optimal control theory; Multi objective control; Observer theory; Nonlinear control theory; Stability theory; Quantitative fault detection and isolation methods; Integration of control and fault detection; Control of Induction Motors; Control of Compact Disc players; Control systems with optical sensors; Roll damping of ships by rudder control; Control of laser scanners.

International research commitments:

- Associate editor for International Journal of Robust and Nonlinear Control.
- Member of editorial board for International Journal of Control. Guest editor for special issue of International Journal of Robust and Nonlinear Control.
- Junior past joint chapter chairman for IEEE Control Systems Society and IEEE Society on Robotics and Automation
- Member of IFAC technical committee on robust control
- Member of IFAC technical committee SAFEPROCESS

Ole Sørensen

Born June 4, 1940
MScEE 1965. Ph.D. degree in 1994
Associate Professor since 1969
Research interests: Optimal Control and Neural networks in control applications.

Claus Thybo, Ph.D. Student

Born January 12, 1966
MScEE 1995
Research interests: Supervisory Control, Fault detection and System Identification. Control of HVAC systems.

Klaus Trangbæk, Ph.D. Student

Born August 11, 1973
MscEE 1997
Research interests: Robust control. Nonlinear control.

Rafal Wisniewski,

Born May 16, 1968
MScEE 1992, Ph.D. degree in 1997
Assistant Professor since 1997
Research interests: Nonlinear control. Periodic systems. Attitude control.

Jørgen Østergaard

Born July 31, 1944
BScEE 1967
Associate Professor in 1974. Reading Professor since 1990. Pro-Rector since 1993.
Research interests: Multimedia and Technology based Learning

Administrative and technical staff:

Iben H. Henriksen, Department Secretary
Jette Damkjær, Students' Secretary
Gitte L. Madsen, Academic administrator

Ole Jørgensen, Technician
Aage Nielsson, Technician

Peter L. Petersen, Laboratory Engineer

Esben Haabendal Sørensen, Student Assistant
Jes Pape Thomsen, Student Assistant
Hans Christian Schøien, Student Assistant
Kenneth A.H. Kilter, Student Assistant
Erik Ringørn, Student Assistant
Enrique Vidal Sanchez, Student Assistant
Ivar Sigurgislason, Student Assistant
Jesper Sandberg Thomsen, Student Assistant
Carsten Callesøe, Student Assistant

3. RESEARCH ACTIVITIES

Laboratories.

3.1 Heating and Ventilation Automatic Control Laboratory (HVAC)

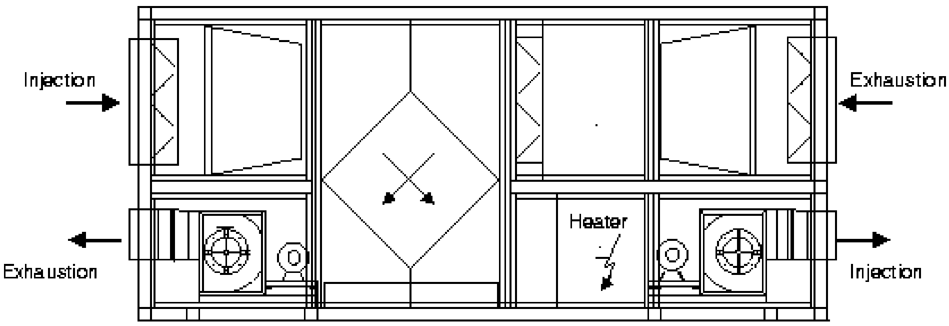
Researchers: Henrik Rasmussen, Claus Thybo and Per Brath.

The laboratory is supported by Danfoss Drives A/S and The Faculty of Engineering and Science at Aalborg University.

The purpose of the laboratory is to serve as a test facility for research and development of different control strategies to get good indoor air quality.

The HVAC system is constructed by Servex Ventilation A/S Denmark.

The HVAC plant:



The components of the HVAC plant are:

- Components at the inlet air flow path
- Inlet damper controlled by a servo motor.
- Dust filter.

- Cross heat exchanger.
- Cooler (not operational at the moment).
- Electrical heating zone (3x6[kW] elements).
- Fan driven by 0.75[kW] AC-motor with encoder. It supplies approximately 1000[m^3/h] at a pressure at 713[Pa] when running at 1500[RPM].

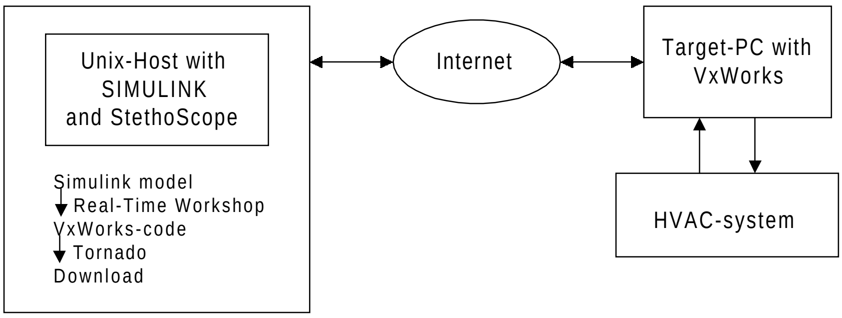
Components at the inlet air flow path:

- Outlet damper controlled by a servo motor.
- Dust filter.
- By-pass damper controlled by a servo motor.
- Cross heat exchanger.
- Fan driven by a 0.75[kW] AC-motor. It supplies approximately 1000[m^3/h] at a pressure at 713[Pa] when running at 1500[RPM].

The two 0.75[kW] AC-motors are driven by two VLT frequency converters from Danfoss Drives A/S.

Besides control activity, it is also a purpose to maintain and develop a flexible test laboratory for control of HVAC systems based on Simulink models. The flexibility of the HVAC-plant is obtained by using software including Tornado/VxWorks, which makes it possible to control the HVAC-plant by Simulink blocks, resulting in a very flexible test system.

The principle of the set-up of the HVAC-plant VLT® and the software is shown in the following figure:

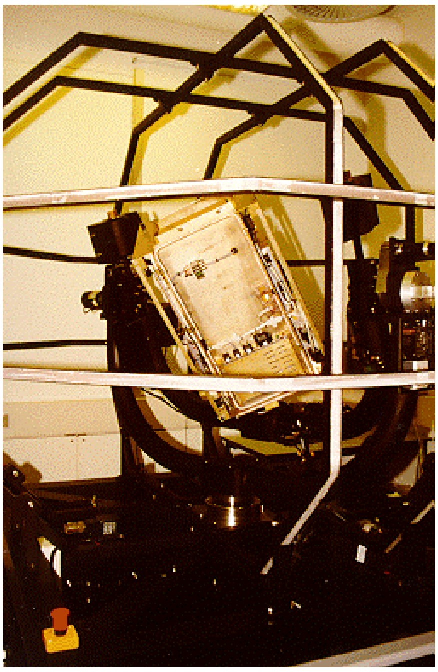


3.2 Satellite Laboratory (SatLab)

Researchers: Mogens Blanke, Per Kromann and Troels W. Udsen.

The facility supports research projects and education in a new specialisation at M.Sc. level in space technology.

The laboratory is supported by C.W. Obel's Foundation, Fabrikant Mads Clausen's Foundation, A/S Fisker og Nielsens Foundation and The Faculty of Engineering and Science at Aalborg University.

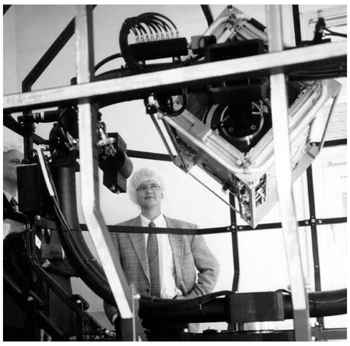


The Satellite Laboratory

The purpose of the laboratory is to provide a laboratory with conditions as similar as possible to those experienced by satellites in space. SatLab provides facilities for physical simulation of satellite motion in space, and facilities for simulation of important parts of the space environment. Additional instrumentation enabled calibration of sun-sensors for the ØRSTED satellite. Environmental test facilities include thermal vacuum and vibration. The sun-sensors were in-house tested to the full vibration level for a qualification acceptance and cycled in temperature from -15 to +110 degrees Celcius while remaining in high vacuum for up to one week.

The Satellite Laboratory is used as a testbench in a number of research projects. This includes autonomous control methods for micro satellites, nonlinear control, robust control, and safety aspects in control systems.

The laboratory was inaugurated by Minister of Research Mr. Frank Jensen at a celebration in June 1995, where several notabilities from research and space science participated.



The Minister is inspecting the satellite rotating slowly on its air bearing.

The geomagnectic field in orbit is replicated in the laboratory by three perpendicular sets of Helmholz coils where 10 A current can produce up to ten times the field strength actually experienced by a satellite in orbit. The magnification has been chosen to reduce any disturbances from magnetic buildingmaterials within the site at Fredrik Bajers Vej 7.

SatLab laboratory arrangement

The SatLab laboratory facilities are installed in two laboratory rooms. The heart of the test facility with the satellite model is placed in the test facility room, which has a clean room status. The second room is used for control and monitoring of ongoing experiments. The experiments are controlled and monitored from the experiment computer. An experiment computer is also used for planning of new experiments and for preexperimental analysis of acquired data.

The SatLab test facility
The test facility enables the satellite model to rotate freely under influence of the gravitational field, nearly as frictionless as a real satellite moves in outer space. Suspending it in a spherical air bearing, which allows nearly frictionless rotation over a limited angle, enables rotation of the satellite model. As 3D frictionless rotation of the satellite model must be obtained, the air bearing is supported by gimbals so that unlimited rotation in all directions is possible. The gimbal system has two orthogonal rotation axes. Both gimbals are guided by a servo system with actuators, control computer and angle sensors.

Research Projects.

3.3 Neural Networks in Control Applications

Researcher: Ole Sørensen.

Within control engineering the task of modelling the object to be controlled is often very laborious and time consuming. Adaptive control strategies involving different kinds of system identification techniques constitute one way of overcoming the above problem. Adaptive control schemes are most frequently based on assumed knowledge concerning the mathematical structure of a feasible model. In dealing with the model parts for which such knowledge is not available, alternative techniques therefore have to be applied.

Neural networks offer the possibility of approximating arbitrary continuous functions to any desired degree of accuracy based only on the knowledge of domain and range of such functions. The approximation is achieved mainly by selecting an appropriate structure, which for neural networks degenerate to the selection of a number of neurones, and also by tuning the internal network parameters by applying training algorithms which closely resemble the identification algorithms applied within system identification and adaptive control. From a control engineering point of view, neural network techniques might be considered simply to be the combination of universal structure and identification algorithms alternative to the ones traditionally applied within the field of control engineering. As such, neural networks are strong candidates for applications within prediction and simulation of natural phenomenon as well as simulation and control of industrial processes.

Within the area of practical application one research project is concerned with the use of the standard Multi Layer Perception (MLP) for controlling and observing a Thermal mixing process which is both non-linear and multivariable. Different concepts are investigated from simple feed forward schemes to complex state feedback schemes involving non-linear neural network state observers. Practical problems such as the selection and pruning of network structures as well as the collection of representative training data are considered.

Results are reported in [6.2.9], [6.3.39], [6.3.40], [6.4.1] and [6.5.1]

3.4 Modelling and Control of a Pitch Controlled 400kW Wind Turbine

Researchers: Torben Knudsen, Palle Andersen, Steen Tøffner-Clausen and Morten Knudsen.

Co-operation: Institute of Automatic Control Systems, The Technical University of Denmark. Test Station for Wind Turbines, RISØ, Vestas Wind Systems A/S and University of Strathclyde Glasgow.

Presently three main methods for controlling horizontal axis wind turbines exist, passive stall control, constant speed with pitch control and simultaneous speed and pitch control. They all have advantages and disadvantages and from an economical point of view it is not yet clear which method is to be preferred.

The main purpose of this project was to compare a modern robust controller with the existing PI type controller on a constant speed pitch controlled wind turbine. This includes designing a full-scale experiment and finding suitable statistical methods for the comparison.

The controllers
The controller objectives are to make a balanced minimisation of power variations, pitch angle velocities and mechanical loads.

The pitch actuator is highly nonlinear. Hence, it is wise to split the controlled system into an inner loop where the pitch angle is controlled and an outer loop where the power is controlled. The existing as well as the new controller are using this concept.

In the existing controller nonlinear static blocks are used in both loops for scheduling purposes. For the linear parts classical Pand PI controllers are used. The new controller is based on Robust H_∞ control which minimises a norm that is based on the output power variation and the pitch angle velocities.

The necessary model for the robust controller design is mainly based on system identification using experimental data. Both linear and nonlinear models are estimated.

Comparing controllers by full scale test

When planning the experiment, the most important issue is to reduce the impact of varying wind conditions. Switching between the controllers every 2 minutes and using a statistical method designed for this particular experimental set-up has done this. The experimental data consist of output power, pitch angle and tower bending measured at 30 Hz for 61 minutes.

The test results obtained showed that the new controller gave a significant 20% reduction in pitch speed rms compared to the existing one. The differences in output power rms were very small and insignificant which also was the case with tower bending. However, for the output power and especially first tower bending, the new controller results in a variation of lower frequencies, compared to the existing one. This is an improvement from a life time point of view. Concluding, the new controller obtains the same performance with less pitch activity and better attenuation of the 3P frequency and is therefore an improvement.

Results are reported in [6.3.21], [6.3.42] and [6.5.5]

3.5 A New Method for Estimating Parameters in SISO Models

Researcher: Torben Knudsen.

The statistical properties of an estimator are some of the most important issues to work with. Well-established results about this issue already exist. Ljung has proved that under weak conditions the prediction error method (PEM) is consistent and if the stochastic part is normally distributed, then it is also asymptotically efficient. Naturally, it is important to know that an estimator has good asymptotic properties. However, what is really required is an estimator, which has good properties for a limited number of observations because that is what is used in practice.

The project concerns the problems that occur when parameters have to be estimated, and the amount of data is limited. The focus is on how to initialise the predictor part of the procedure, because this can have a significant effect on estimator properties.

The project starts with a discussion of the transient in the prediction error. Then the problems for the standard estimator, which are a consequence of these transients, are discussed. Some possible solutions are presented and one is selected and developed. The method developed has been compared to the standard solution through simulations. A method based on back forecasting has been developed. It is compared to several procedures from the System Identification Toolbox written by Lennart Ljung. Generally, the developed method is among the best, and in a number of cases it is superior.

This research was initiated in the last planning period where the ARMAX model structure was treated. In the present period the theoretical description of these results have been improved and they have been extended to cover general SISO transfer function model structures.

Results are reported in [6.2.4] and [6.3.20]

3.6 Control of Heating Ventilation and Air-Conditioning systems

Reaserchers: Henrik Rasmussen, Claus Thybo, Per Brath.

Some of the most energy consuming installations in buildings are pumps and fans used in HVAC applications. One way of reducing the energy consumption is to use a variable speed drive to control the speed of the fans and the pumps. As a side effect we gain some reduction of mechanical wear and tear of belts, bearings, valves etc. This will provide a reduction of the overall maintenance costs of the equipment. It will also give a reduction of the acoustics noise level when lowering the speed of the controlled device.

Another important issue for the energy consumption is tuning of controllers. A lot of the controllers used in industries today run with the factory settings, which normally give poor performance. One reason for this is that the commissioning time often is very time consuming.

As the amount of supervisory function increases in modern building management systems it is much easier to evaluate the performance of the control loops. Therefore, we have to continuously put more effort into improvement of the control performance (e.g. response time, overshoot, damping, etc.). At the same time we must assure that the energy consumption is kept at a minimum level.

Another issue it to keep the Indoor Air Quality (IAQ) at an acceptable level according to national and international standards. This means that more work must be put into tuning of the controller if the demands on performance must be fulfilled.

A co-operation between Danfoss Drives A/S and Department of Control Engineering concerning Autonomous Control has been motivated in the projects:

- Autonomous Control of Inverter Fed Induction Motor Drive Applications
- Fault Detection and Isolation in Industrial Drives

The objectives of these projects are:

- To develop a concept for auto-tuning, which include handling of an unknown process driven by a nonlinear, but model based known actuator
- To analyse, develop and implement methods to improve system robustness.
- To develop new concepts for Demand Controlled Ventilating (DCV) Systems.
- To analyse and develop schemes for fault detection and isolation of different sensor signals.
- To test the final concept on different HVAC systems using frequency converter driven fans.

3.7 Technological renewal and learning processes in connection with control room work

Researcher: Lars Peter Jensen

The research activities are concerned with monitoring and control room work in the processing industry. We operate with a method close to the company and implementation, where (re)-design of control rooms and working environment dimensions such as competence and qualifications are included. A central feature is to make experiments by initiating a common learning process for the central actors in the company, the suppliers and the participating cross-discipline research team, in order to improve the working environment during technological and organisational changes.
Within industries with a high degree of automation, like the processing industry and related industries, there is a need for readiness, knowledge and awareness when technical or organisational changes are on the agenda. There might be many reasons for changes, e.g. promoting efficiency, renewal of the automation systems, rearrangement of the production etc. No matter what the reasons for the changes are, it is important to have the human factor in focus for the technical or the organisational change. We find it necessary to have a holistic point of view on the possibilities and consequences of the working environment and working conditions before, during and after the changes.

In the beginning of 1995 Ass. Prof. Lise Busk Kofoed (Department of development and Planning) and Ass. Prof. Lars Peter Jensen (Department of Control Engineering) formed a cross-disciplinary research team within the University and started raising money for external support of the project. This succeeded within a year with the participation in the research programme: Working Environment & Technological Development (WETP), starting officially 1/4 1996 and planned to run for three years, and expected to continue for at least two more years. During 1996 the research group was consolidated with Ass. Prof. Torben Rosenørn (Department of Chemistry and Applied Engineering Science) and Ph.D student Gorm Simonsen (Department of development and Planning).

During the whole period our activities have been concentrated on finding, starting and running a case study. We have succeeded in finding a large Danish processing industry that has to improve its efficiency in all areas, e.g. reduction of the number of employees from 200 to 150 - 170 before the end of this century.
An international consulting company is hired to supervise the change process and their message was that they could handle a change process with no frustrations. We have been invited to study the process. We are also allowed to advise the consultants, the employees and the management, and we are able to interfere in the change process and develop as well as test or examine new ideas.

The first 4 months of 1997 we have deliberately been observing the process closely rather than participating because we did not want to disturb the confusing start of the change process. Instead, we have made lots of observations of the working situation in the control room. We have been present at the different consultant activities during the process, and participated in all the co-operation committee meetings. Furthermore, we have been interviewing the consultants and some of the employees with special tasks according to the consultants' strategy.

The rest of the year we have been doing experiments with the employees using an idea of our own:

The experimentarium.
The purpose of the experimentarium is to give employees, managers and developers/consultants the opportunity to develop, and to test new ideas, and to carry out experiments in an experimental situation. They have the alternative of doing it separately or together in mixed groups. In practice the experimentarium can be placed in a concrete room; but the specific arrangement is dependent of the experiments going on, e.g. training and development by distance learning. The experimentarium has to be seen/understood more like a virtual room for different activities.

After the first two small experiments in the experimentarium the participants expressed that they had seen that together they possessed a large amount of knowledge, and they experienced that their individual differences were an advantage. They had also learned to see each other as experts on different fields, and during the work they observed that a holistic view on a topic resulted in a better analysis and it is necessary to analyse and assess consequences before implementing solutions.

Having succeeded the first experiments, we see a great potential in the ideas of using the experimentarium to establish common learning processes that can help companies during organisational changes towards a learning organisation.
It is our believe that this kind of experimentarium activities can overcome a lot of frustrations in changing processes, and improve the working environment, because the operators and the engineering department can combine their knowledge to develop better working tasks, and at the same time obtain mutual respect.
The experiments will continue at least to the end of 1999 as we are working with the case until then, and our findings will be published continuously.

Results up until now are reported in [6.1.2], [6.3.14], [6.3.15] and at a National workshop arranged by the WETP programme, 26/5-97.

3.8 Multimedia and Technology Supported Learning (MMTL)

Researchers: Morten Knudsen, John Nørgaard Nielsen, Jørgen Østergaard, Ole Borch, Jens Dalsgaard Nielsen, Niels Jørgensen.

While the exponential accumulation of information and rapid changes in technology necessitates on-going education, in particular for engineers, the new information and communication technology offer exciting prospects for university education in the future. In distance education, technology can help breaking the constraints of place, time and pace. This is often an attractive alternative, in particular for continuous education. In addition, computer based education is reported to increase learning effectiveness, i.e. learning speed as well as retention, and is most often accepted very positively by the students.

The purpose of this project is to initiate and co-ordinate the Department's activities, as well as performing research, within the areas:

- Multimedia in general
- Technology based learning, distance learning and continuing learning
- Technology based administration, organisation and planning of education

The group follows the relevant technological, pedagogical and political developments, locally and globally, and participates in various committees. Proposals for research projects are prepared, research projects are carried out and the results published. Technology based educational material, e.g. computer aided courses, is developed, implemented and evaluated.

3.9 An interactive multimedia computer-based instruction in 'Simulation and Experimental Modelling' (XMODEL).

Researcher: Morten Knudsen

The objectives of this project are to develop a general concept for flexible computer-based instructions for distance learning in the field of Control Engineering and to develop a multimedia based instruction in 'Simulation and Experimental Modelling'

A CD-ROM based interactive multimedia instruction in 'Simulation and Experimental Modelling' is developed. It consists of hyper media material with questions and examples. The authoring program Medi8or is used. Part of the content is based on a new sensitivity approach for direct estimation of physical parameters. The presentation is inspired by Solomans inventory of learning styles. To enhance active learning and motivation of real life problems, use of the simulation tool Matlab is integrated in the instruction.

3.10 A generic interactive package for system engineering courses and applications (GIPSECA).

Researcher: Morten Knudsen

The purpose of the project is to research into the development of a teaching scheme for integration of a number of engineering disciplines under the generic theme of System Engineering, and design and implement an interactive and networked multimedia package for use in academia and industry.

Detailed objectives are:

- Provide a standard for teaching and training of Systems Engineering for implementation on a wide scale within Europe and the Mediterranean region
- Conduct extensive discussions and collaborative interchange of ideas to ensure the applicability and the generic nature of the package as a

standard at both undergraduate and postgraduate levels. - The design and implementation of an interactive networked package based on being used on the Internet and on CD-ROM, to cater for complex multimedia actions.

- The package may be used in conjunction with existing teaching schemes (e.g. distance learning) or for on-site training for individuals in industry.
- Seek the advice and active involvement of industry.
- Conduct analytical studies and workshops/seminars during the period to disseminate results and ensure operation within acceptable European, regional and national standards.
- Implement a pilot system, linking different institutions to the consortium.

3.11 Estimation of Physical Parameters

Researcher: Morten Knudsen.

Estimation of physical parameters is an important subclass of system identification. The specific objective is to obtain accurate estimates of the model parameters, while the objective of other aspects of system identification might be to determine a model where other properties, such as responses for certain input in the time or frequency domain, are emphasised. Consequently, some special techniques are required, in particular for input signal design and model validation. The model structure containing physical parameters is constructed from basic physical laws (mathematical modelling). It is possible and essential to utilise this physical insight in the input design and validation procedures.

This project has two objectives:

- To develop and apply theories and techniques that are compatible with physical insight and robust to violation of assumptions and approximations, for system identification in general and estimation of physical parameters in particular.
- To apply the new methods for modelling of specific objects, such as loudspeakers, ac- and dc-motors wind turbines and beat exchangers.

A reliable quality measure of an obtained parameter estimate is a prerequisite for any reasonable use of the result. It is also necessary for experiment design, in particular for determination of optimal input signals. The prevalent quality compared to this approach is

- More independent of assumptions and approximations, e.g. about the noise,
- Due to a geometric interpretation (the "sensitivity ellipsoid"), it is very compatible with physical insight, and iii) it is applicable for physical parameters as well, whether these parameters are estimated directly, or indirectly from the discrete-time parameters. Under the usual assumptions about the noise, a simple relationship between the sensitivity and the relative parameter variance and confidence ellipsoid is demonstrated. The relation is based on a new theorem on maxima of an ellipsoid.

The procedure for input signal design and physical parameter estimation is tested on a number of examples, linear as well as nonlinear and simulated as well as real processes, and it appears to perform very well.

Results are reported in [6.3.16], [6.3.17] and [6.8.11]

3.12 Process Optimizing Multivariable Controllers for Power Plant Applications

Researchers: Tom S. Pedersen, Palle Andersen, Jan Henrik Mortensen, Mads E. Hangstrup.

Co-operation: ELSAMPROJEKT A/S and Skærbækværket I/S

Introduction of multivariable controllers in power plants.
Control systems for power plant boilers are often composed of a number of SISO controllers supplied with a few feedforwards. Due to multivariable effects this often leads to excessive temperature gradients in the boilers resulting in a reduced performance and lifetime of the plant. Introduction of multivariable controllers in control of power plant boilers may improve control performance significantly.

The purpose of the project is to develop an optimising control system for improving the load following capabilities of a power plant unit. The system is implemented as a complement producing additive control signals to the existing boiler control system, a concept, which has various practical advantages in terms of implementation and commissioning.

Simulation

In order to ensure a safe environment, in which to develop and test new controllers, a dynamic simulation model of the boiler, turbine and the existing control system of Skærbækværket unit 2 (SVS2) has been set up. According to comparisons between simulation results from the SVS2-simulator and the real plant, the SVS2-simulator gives a good picture of the process dynamics.

The controllers.

The objective was to improve the load following capabilities of the existing power plant units. During fast load changes the major problem is to keep certain critical variables (e.g. steam temperatures) within predefined limits. As optimising controller a LQG-controller is used. Two different methods of introducing feedforward compensation have been examined: one method with the feedforward compensator integrated into the LQG-controller, in the other it has been separated from the LQG-controller, but is co-ordinated via the state estimator. The feedforward signal is the load demand. Because the dynamics of the boiler process change with the operating conditions the LQG-controller is gain-scheduled.

Field tests on Skærbækværket unit 2.

A gain-scheduled LQG-controller with co-ordinated LQ-feedforward has been designed and implemented in four different load points covering the full normal operating range of the boiler. It was found that the limiting agent of the SVS2 boiler's load following capability is steam temperature fluctuation before the 1st attemperator. According to the practical tests it is possible to almost fully compensate for the fluctuations in this steam temperature during a fast load change using the LQ-feedforward. Long term tests with the LQ-feedforward compensator at SVS2 have come out with good results. Tests of the LQG-feedback control have demonstrated that disturbances from the boiler can bee suppressed with as much as 37%.

Results are reported in [6.3.31],[6.3.23],[6.3.21],[6.3.11] and [6.6.10].

3.13 Semi-global H∞ State Feedback Control

Researcher: Jakob Stoustrup

From an applicational point of view the theory of local $H\infty$ control has a severe drawback: It does not give a bound on the state trajectories, but merely states that it is valid for bounded trajectories. In fact, a linear controller based on the linearization in an equilibrium point might even do better in practice than a local nonlinear $H\infty$ controller. Moreover, it can be argued that the real motivation for nonlinear control theory is applications where the plant is operating in a significant range of operating points. Otherwise, linear control theory will work in most cases.

On the other hand, to compute a global nonlinear $H\infty$ control is not realistic in most practical cases since it basically requires finding an analytical expression for a global solution to a Hamilton-Jacobi-Isaacs equation.

This is the main motivation for the project in semi-global $H\infty$ state feedback control which aims at deriving a method for designing $H\infty$ controllers constraining state trajectories to a region of the state space rather than in the whole state space or just in a single point. The regions could for instance be specified in terms of invariant sets, and the hope would be to obtain generalisations of local h∞ results. Such results have indeed been established in the project, and moreover, the computational methods that apply to local $H\infty$ control extend directly to the obtained semi-global $H\infty$ results. This constitutes a much more practical theory for nonlinear control systems where also oscillating and other non-stationary modes of operation can be dealt with.

Results are reported in [6.3.9]

3.14 Integrated Fault Detection and Control

Researcher: Jakob Stoustrup

In the control of industrial systems, it is rare that a control system functions continuously without shutdown throughout the scheduled life cycle of the plant and controller hardware. Due to wear of mechanical and/or electrical components both actuators and sensors can fail in more or less critical ways. For safety critical processes it is of paramount importance to detect when faults are likely to happen, and to identify as fast as possible which faults have taken place.

To meet such industrial needs, a number of schemes for Fault Detection and Isolation (FDI) have been put forward in the literature on automatic control. Most of the papers appearing in journals and in conference proceedings have dealt with the design of filters, which monitor a process, and generate alarms when faults may have occurred. In most cases, the filters are model-based devices which act independently of the computer implemented digital controllers. In this project, however, the advantages of combining the control algorithm and the FDI filter in a single module is studied, both whether such a combined module would be beneficial in terms of implementation and reliability, and whether it is preferable in terms of security and control performance. A relatively simple methodology to design such combined modules has already been described.

On one hand, results obtained have shown that the quality of control and the quality of detection will not improve by using the integrated design, compared to individual designs of the two components, provided that a good nominal model is available. This result is shown to be very general.

On the other hand, if the quality of the available model is poor, the design of the control system and the design of the diagnosis system have to be undertaken simultaneously, in order to improve the overall functionality.

Results have been reported in [6.2.8], [6.3.27], [6.3.28], and [6.3.37]

3.15 Multiobjective Control

Researcher: Jakob Stoustrup

The area of robust control has received tremendous attention in the control literature recently. Especially, $H\infty$ theory has been in focus since its breakthroughs during the 1980's.

$H\infty$ control is mainly motivated by the following two applications. First, if the modelling errors are assumed to be bounded in $H\infty$ norm by a known bound, bounding a transfer function determined by the plant and the controller in $H\infty$ norm guarantees robust stability. Second, formulating optimality conditions as frequency domain bounds for a number of transfer functions, $H\infty$ theory can be applied as a loopshaping tool.

In a limited number of cases, robust stability suffices, but in most applications it is required to satisfy optimality specifications as well, and hence some kind of loopshaping techniques has to be employed.

In the mainstream literature, it is suggested to use $H\infty$ theory for such purposes by stacking control objectives as, e.g., in the so called mixed sensitivity approach, where a design criterion is formed by constructing huge composite transfer matrices. The motivation for the mixed sensitivity approach is that a controller which renders the norm of the giant transfer matrix smaller than some number, also does so for each entry of the involved submatrices, which is usually the original goal.

The problem, however, which is addressed in this project, is that an approach based on a criterion like the popular mixed sensitivity criterion can be rather conservative since all possible cross-couplings between inputs and outputs are considered, which might not be motivated from physics. Moreover, the design process might be very complicated, since all design criteria are merged into a single one, making weightings difficult to interpret. In effect it might not be possible to meet the performance specifications by this approach, in spite that there might actually exist an admissible controller which bounds each individual sensitivity sufficiently, which is just not encountered by the method. For handling this design problem in a more convenient way, a multi objective design approach must be employed. By applying a multi objective design method, the hope is to remove or reduce the conservatism due to the cross-coupling terms.

A number of results have been obtained which in a surprisingly simple form offer efficient ways to overcome the problems in the most popular approaches.

Results have been reported in [6.2.7]

3.16 Performance Analysis for Systems with Parametric Uncertainties

Researcher: Jakob Stoustrup

Robust performance analysis for uncertain control systems, which is now receiving a great deal of attention, is a relatively new area in comparison with robust stability analysis. For linear time-invariant systems, the H_2 performance metric arises naturally in a number of different physically meaningful situations. The H_2 performance of a linear time-invariant system is measured via the H_2 norm of its transfer matrix. As long as this H_2 norm is less than a given upper bound, the design can stop, and there is no need to seek the minimal norm due to robustness considerations. Suppose the H_2 norm of a nominal (stable) system is less than a given upper bound, then the question is whether this is still less than this upper bound after suffering the parameter perturbation? or alternatively, how to find the "maximal domain" for perturbation parameters under stability and H_2 norm constraints? This project considers the latter problem, and aims at calculating the maximal (nonlinear) perturbation interval or radius in perturbation parameter space. The project tries to extend previous work in the literature, which has been restricted mostly to a fixed parameter domain and affinely linear perturbations.

The aim is not only to compute the maximal perturbation radii subject to performance constraints, but also the average performance over a fixed perturbation set.

Necessary and sufficient conditions have already been obtained and have been reported in [6.2.11] and [6.3.47]

3.17 Loop Transfer Recovery

Researcher: Jakob Stoustrup

Loop Transfer Recovery (LTR) emerged as a link between classical control and robust control. The idea is roughly to separate the process of designing the feedback and the observer gain parts of a dynamical control into two steps, without losing control of robustness margins, etc. First, a static state feedback gain is computed, the behaviour of which is then subsequently recovered by observer techniques.

Most papers in the literature address the LTR problem in continuous time. Although there are certain similarities between the LTR of continuous and discrete-time systems, fundamental differences also exist. In the literature, it is well established that an arbitrarily specified target loop transfer function is recoverable if the continuous-time system is minimum phase and left invertible. However, this is not true for discrete-time systems, where in general, it is not possible to achieve asymptotic (or exact) recovery for a free target design. However, it is possible to overcome some of these problems by including an integral term in the full-order observer. By using this PI-observer in connection with LTR design, it is possible to obtain time recovery, i.e. recovery as time tends to infinity. The continuous-time case has previously been thoroughly investigated by the international group of researchers involved in this project, which in contrast is devoted to the discrete time problem.

Results so far have established that it is also possible to obtain time recovery in the discrete-time case by using a PI-observer for both minimum phase as well as for non-minimum phase systems.

Results have been reported in [6.2.6]

3.18 Industrial Multivariable Control

Researcher: Jakob Stoustrup

In several industrial environments as e.g. power plants, installing a full multivariable controller is difficult due to safety requirements. Often the starting point is a plant, which is already controlled by several single loop controllers, for instance of PI or PID type. The new controller is then introduced in parallel, varying the control signal continuously by a tuning procedure. The problem with this approach is that open loop unstable controllers can not be applied, since they are not stabilised by the plant for small values of the tuning parameters. This is problematic, since many controller design techniques, based on modern optimisation, generically will suggest unstable controllers.

The aim of this project is to find a general scheme for installing multivariable controllers in industrial environments. Results obtained achieve this by simple remedies, and the results also have applications to control by gain scheduling.

Results have been reported in [6.3.36]

3.19 Decentralized Control

Researcher: Jakob Stoustrup

The problem of decentralised control is addressed in this project, i.e. the problem of designing a controller where each control input is allowed to use only some of the measurements. Results show that for such problems there does not always exist a sequence of controllers of bounded order, which obtains near optimal control. Neither is there an infinite dimensional optimal controller. Using the insight of the line of proof of these results, a heuristic design algorithm is proposed for designing near optimal controllers of increasing orders.

Results are reported in [6.3.38]

3.20 Determination of Loudspeaker Models

Researchers: Morten Knudsen and Jørgen Grue Jensen.

New technology has enabled large improvements in sound reproduction, and the loudspeaker is more than ever the weak link in the chain. To improve loudspeaker units as well as loudspeaker systems, better loudspeaker models are essential. Also faster and more accurate methods for determination of the traditional loudspeaker parameters are useful.

Using a system identification technique a method for determination of the loudspeaker parameters has been developed. In order to determine all parameters from just one experiment, the cone displacement is measured in addition to the input voltage and current.

For some loudspeakers the traditional model is inadequate. It has therefore been expanded to incorporate creep in the suspension. Three creep model structures are developed, partly from viscoelastic theory, partly from empirical considerations. The models are simulated in the frequency domain as well as in the time domain, and the physical parameters are determined directly.

Experiments on three different woofers demonstrate that the expanded models are able to fit the measured input/output data much better than the traditional model, even with just one extra parameter. The expanded model structures are further supported by the results from cross validation experiments. Because an inappropriate model structure may be the cause of systematic errors, the expanded models can improve accuracy in loudspeaker parameter measurements.

The major innovative value of the work is a faster and potentially more accurate method for loudspeaker measurements and new and better model structures. The quickness of the method permits a measurement of each individual low-frequency loudspeaker as it leaves the assembly line. So far this had only been possible for high-frequency speakers.

Besides providing more accurate parameter measurements, the expanded model structures, including creep, are necessary for determination of nonlinear loudspeaker models. The models have been used for design of control based nonlinear observers.

Results are reported in [6.1.1] and [6.3.16]

3.21 Control of Induction Motor Drives

Researchers: Henrik Rasmussen, Jakob Stoustrup, Per Brath Jensen, Claus Thybo, Klaus Trangbæk

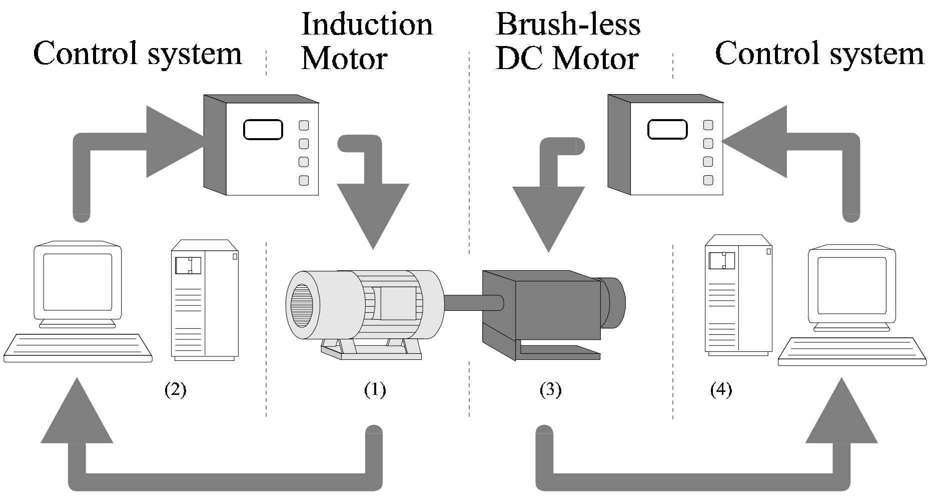
Recent development within information technology and power electronics makes it possible to realise AC-motor drives which may compete with DC-motors with respect to cost and reliability. Therefore the technology of computer controlled AC-machines is developing rapidly, and is the subject of research in universities as well as in industrial companies. In recent years the Department has had a profitable co-operation with two major Danish companies on control of induction motors.

In co-operation with Danfoss A/S Transmission Group, the Department has carried out several projects on control of AC-machines. Self-tuning field oriented controllers for induction motor applications have been developed with good results. The research co-operation is now focusing on auto tuning, fault handling and supervisory control for developing autonomous controllers to be used in frequency converters for induction motor drives.

In co-operation with Grundfos A/S, the Department has carried out several projects dealing with sensor-less and nonlinear control of induction motors. A new method to control induction motors based on nonlinear state feedback has been developed and research to improve the method is still going on.

Because the induction motor is a nonlinear system with significantly time varying parameters, the intention of the project is to compare commonly used methods as e.g. field-oriented control with methods based on robust and nonlinear adaptive control. To construct robust adaptive controllers it is crucial to develop methods that exploit information on unmodelled dynamics and parameter uncertainties. It is also important to understand the interaction between control and identification.

It is also a main purpose to maintain and develop a flexible test laboratory for induction motors giving facilities for test of control strategies based on Simulink models. The figure shows the main components of the test-bench. By using Tornado/VxWorks it is possible to control the motor by Simulink blocks, resulting in a very flexible test set-up.



Main subprojects are:

- Self-tuning torque control of induction motors for high performance applications
- Robust nonlinear control of induction motors
- Fault Detection and Isolation in Industrial Drives

Self-tuning torque control of induction motors for high performance applications

A co-operation between Danfoss A/S Transmission Division and Aalborg University, Department of Control Engineering concerning clarification of the potential of modern control theory used in a standard drive system has motivated the present project.

The purpose of the work is stated in the following:

- To analyse and develop strategies for fast torque control of induction motors well suited for automatic tuning.
- To analyse and develop methods for automatic tuning of the applied controllers.
- To develop robust methods for adaptive field oriented control.
- To test the final concept on different motors

Robust nonlinear control of induction motors

Robust H_∞ theory provides methods for dealing with uncertainties in the plant model. These uncertainties can originate from:

- Poor estimation of plant parameters
- The model class not containing the actual plant dynamics, for example due to nonlinearities.
- Variations in the plant dynamics over time, for example due to temperature changes.

In the induction motor the rotor resistance is highly dependent on temperature and the interval in which it changes is fairly well known.

Work has commenced on using the robust H_∞ theory on the induction motor to design a controller robust to changing rotor resistance and certain other uncertainties.

To cope with the inherent nonlinearities of the plant a method developed by Andy Packard is used. A model of nonlinearities is built into the controller to allow the problem to be rewritten on a standard form. Hereby standard linear model design methods can be used.

Autonomous Control of Inverter fed Induction Motor Drive Applications

The amount of inverter fed induction motor drive applications has increased and will still increase in the following years. This will lead to additional consumption of electrical power world wide when the applications are controlled by electrical drives. A demand of driving the AC-motor and thereby the application in an energy efficient right manner will arise. This will give great challenge to develop new and better control strategies for such applications.

A cooperation between Danfoss Drives A/S and Department of Control Engineering has been established through an industrial Ph.D. project.

The objective of this Ph.D. study is to develop an automatic tuning/supervision of the process controller implemented in the frequency converter. Normally tuning of the controller parameters is a very time consuming work and in some cases almost impossible, even for a skilled control engineer. The result of a manual tuning could easily result in a not optimal running process and consumption of too much energy.

The HVAC, (Heating Ventilation and Air Condition), process is used as case study. The flexible HVAC test laboratory is a great facility for testing the different strategies which are all based on Simulink models. By using the Tornado/VxWorks it is possible to use the Simulink blocks to control the HVAC system given great flexibility.

The main subjects of the work are:

- Automatic Tuning
- Adaption
- Supervision
- Diagnosis

Results are reported in [6.3.31], [6.3.33], [6.3.34], [6.3.35] and [6.6.12]

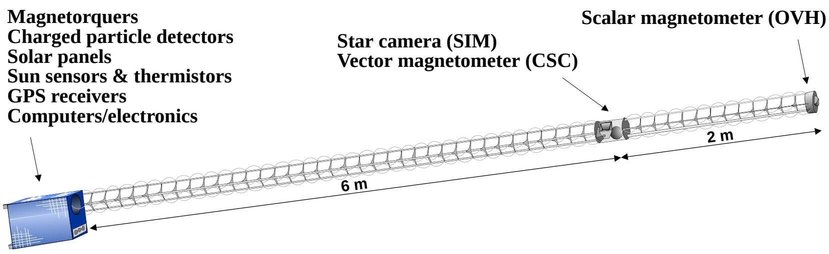
3.22 Attitude Control System for the Ørsted Satellite

Researchers: Thomas Bak, Mogens Blanke, Søren Abildsten Bøgh, and Rafal Wisniewski.

The Department of Control Engineering participates in the design of the first Danish satellite, Ørsted. The project is a co-operative venture between Danish research institutes and space related industrial companies. The Department is responsible for the attitude control system design and implementation.

Ørsted is a 61 kg satellite scheduled for launch by a Delta II launch vehicle in late 1998 from Vandenberg, California. The two primary mission objectives are to measure the main Earth magnetic field and study the interaction with the solar wind plasma.

The satellite is highly autonomous and represents a step forward of international standards in the amount of technology implemented on a micro satellite. Specifications for the attitude control system have been fulfilled through implementation of wide onboard autonomy.



The physical outline of the satellite.

The main body carries antennas, solar panels, electronic equipment, and an eight-meter long boom. The high precision scientific instruments for magnetic measurement are located at the boom tip to avoid disturbances from the main body. The attitude control task is to point the boom away from the earth and the antennas towards the earth during the entire orbit.

Attitude actuators are electro-magnetic coils (magnetorquers) arranged in three axes inside the satellite main body. When the magnetorquers carry currents, the generated magnetic field reacts with the geomagnetic field, and thereby creates a control torque.

The satellite attitude is measured with four sensors:

1. Star imager. Based on a CCD camera taking pictures of the stars
2. Sun sensor. Photo cells indicating the direction to the sun
3. GPS receiver. Provides the satellite position.
4. Magnetometer. Measures the local magnetic field.

The research group is responsible for the controller design, software design, and detailed testing before launch. The controller design is a challenge because both the satellite dynamics and the control actuators are highly nonlinear.

Attitude Determination

The primary attitude acquisition device is the star imager. When the bright objects are within the field of view the star imager is incapable of producing estimates. It is therefore necessary to install a secondary algorithm that computes attitude estimates based on magnetometer and sun sensor measurements.

The nonlinear relationship between vector measurements and the attitude representation calls for a modified Extended Kalman Filter (EKF). The unity norm constraint results in a singularity in the covariance matrix, which is avoided by applying an multiplicative update algorithm. Detailed orbit and geomagnetic simulations have been carried out and simple algorithms for onboard implementation are suggested.

Publications: [6.3.9], [6.3.3] and [6.3.2]

Attitude Control

Magnetic torquing has proved to be an attractive control principle on small satellites where high pointing accuracy is not required. A serious obstacle has been the inherent nonlinear nature of the interaction between the earth's magnetic field and the moment generated bythe magnetorquers.

Geomagnetic field vector variation is used for despinning the satellite from an arbitrary initial tumbling and prepare for boom deployment.
The operational phase control utilises a linearized model of the satellite motion. The observation that the geomagnetic field changes periodically in time is used in the design. Local stability properties of the system are shown via Floquet theory. In the operational phase the satellite is three-axis stabilised with the boom pointing outwards.

Publications: [6.3.45], [6.3.9], [6.3.44], [6.3.43], [6.3.3] and [6.6.16]

Onboard Autonomy
The Ørsted satellite is operated from only one ground station situated in Denmark. Ground contact is limited to approximately 20 minutes each day, which requires a high level of onboard autonomy. In-flight events like hardware faults must be handled onboard to avoid serious impact on the scientific mission or even loss of the satellite.

The attitude control system is combined with a supervisory level that handles the following:

- Mission phase control
- Operational mode control
- Onboard monitoring
- Fault detection, isolation, and accommodation
- Command and telemetry communication with ground

When the level of onboard autonomy becomes extensive and thereby demands a higher level of reliable operation, it becomes inherently more complex for the designer to cover all possible situations and guarantee correct and complete operation. A systematic method, which promotes a complete examination of all possible faults, based on a fault propagation analysis, was developed in the RRELCO programme. This analysis technique was enhanced to cover the problems encountered during the Ørsted development. Special focus has been on methods for the design of consistent supervisor logic that guarantees correctness and completeness.

Software tools are used to support the design task and facilitate easy implementation on computers.

Publications: [6.2.3], [6.3.8], [6.3.9], [6.3.13], [6.3.3] and [6.6.2]

Onboard Attitude Control Software

The onboard flight software is implemented as a fully autonomous real-time system. To achieve maximum reliability and robustness, an object orientated design method called HRT-HOOD (Hard Real Time - Hierarchical Object Oriented Design) has been used. The flight software is implemented as an embedded real-time system on an Intel 80C186 based hardware platform using the Ada language. An attitude control electronics box controls attitude sensors and actuators.

Publications: [6.8.6], [6.8.4], [6.8.7], [6.8.2], [6.8.1] and [6.8.5]

3.23 Geomagnetic Space Observatories (GSO)

Researchers: Thomas Bak, Mogens Blanke, Rafal Wisniewski

The objective of this project is to study the lithospheric fields in the earth's crust: Very low (lower than 250 km) Earth orbiting satellites are needed. The larger atmospheric density in low orbit results in significant aerodynamic drag torques acting. With a conventional satellite design this may result in instability. This project addressed how the instability could be avoided by using aerodynamic drag for passive attitude stabilisation.

Motion of a uncontrolled satellite in very low altitude earth orbit is dominated by the relationship between the two external torquers. Aerodynamic drag torque: usually dominating in the 200 kilometres altitude region. Gravity gradient torque: may be equally important for a small relatively symmetric satellite.

A nominal attitude is considered with an instrument boom carried in the wake. The result is low drag forces while aerodynamic drag torquers are used for compensating gravity gradient effects providing passive stabilisation. An investigation of the pitch dynamics resulted in a nonlinear equation describing the torque applied to the system by aerodynamic drag.

The aerodynamic drag acts in the pitch direction and only pitch dynamics are therefore investigated. The result is a non-linear equation describing the torque applied to the system by aerodynamic drag. Integrating the negative torque yields the potential energy of the non-linear pitch system under influence of gravity gradient, aerodynamic drag and shadowing. The result is a marginally stable system with two equilibria. Another possible source of instability (parametric resonance caused by higher order density harmonics and local wind) was also investigated.

The above analysis of the passive aero-stabilisation has resulted in several design guidelines for GSO. Based on analysis and simulations passive aerodynamic stabilisation was proposed and the performance predicted.

Matlab simulations of GSO subject to aerodynamic drag were carried out with high fidelity models of the small frequency (large period) atmospheric disturbances (MSIS-86 model). The higher frequency contributions were modelled using a local wind model, HWM-93.

Results are reported in [6.5.2] and [6.3.1].

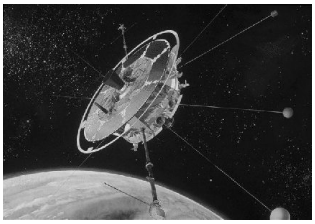
3.24 ASTRID-2/FREJA Attitude Restoration

Researchers: Thomas Bak, Mogens Blanke

Satellites performing auroral investigations carry payload for observing E- and B-fields, etc. A VxB motion induced field, however, contaminate the data. By comparison of the onboard measured magnetic field to a reference field model it is possible to reconstruct the attitude of the satellite with sufficient accuracy to get the VxB corrections to the E-field measurement, thereby enhancing the scientific value of the experiment significantly.

The main objective has been to reconstruct the attitude of the satellites FREJA and ASTRID-2 based on the onboard measured Earth's magnetic field and the satellite position. For ASTRID-2 and FREJA the attitude restoration is proposed to be based on the onboard measured Earth's magnetic field and the satellite position.

At one given instant the satellite position is used to calculate the IGRF (International Geomagnetic Reference Field) model field direction, and the onboard magnetic measurement gives the direction of this known external field in the satellite co-ordinate system. One single magnetometer reading only provides two-ax attitude information and therefore a sequence of measurements therefore has to be used in a recursive filter. Since the relationship between vector measurements and the attitude is nonlinear, an extended Kalman filter is used to estimate the attitude quaternion and angular rates.



The FREJA Satellite

Internal consistency is tested by comparing the measured field magnitude to the model field magnitude and though cross check with coarse sun sensors on the satellites.

3.25 Rudder-roll damping for ships

Researchers: Mogens Blanke, Jakob Stoustrup, Henrik Niemann (DTU), Antonio Tiano (Univ. Pavia, visiting 3 months in 1995-96), Chengen Yang (Dalian Maritime University, visiting 18 months in 1995-97), Gerald Hearns (Univ. Strathclyde, visiting 3 months in 1997)

Rudder-roll-damping (RRD) is a technique for damping ship's roll by means of their rudder. The purpose of an RRD autopilot is to reduce roll motion to the extent possible while simultaneously, maintaining the ships course. RRD is a single input – multi output problem and roll reduction is constrained by a right half plane zero occurring from couplings between sway, yaw and roll motions. Roll motion can not be damped arbitrarily well at all frequencies but an optimal trade-off needs to be found.

Other obstacles in the design of effective RRD control include:

- Sea waves have widely varying spectra,
- The control performance is very sensitive to couplings between steering and roll, and
- Modelling uncertainty of a ships dynamics is quite large
- Rudder control is nonlinear due to constrained flow in the hydraulic steering gear

Experience has shown that the sensitivity of RRD controllers is very high to changes in, e.g., loading conditions of a ship. In order to utilise theoretic control systems design methods to obtain good RRD control, there has been a need to obtain a better understanding of the physic that gives rise to changes in coupling effects. This has been a main task in the reporting period.

RRD autopilot

The international interest in RRD control dates back to 1975 when the first ideas were presented. Intensive research started in the Netherlands and Sweden in the early 1980 ties. In Denmark, RRD research started in 1985 when the Danish Navy decided to specify RRD control as an integral part of the control concept for the Standard Flex 300 new-building programme (Munk and Blanke, 1986).

The result was that a new autopilot was developed that included non-linear Kalman filter estimation of relevant motions, linear quadratic (LQ) optimal feedback using appropriate gain scheduling with ship speed, integrated turn rate controller in the autopilot, and rudder-roll damping (Blanke, et al. 1989).

RRD robust controller design

With 14 sister ships at sea, a unique experience was obtained. It appeared that dynamic couplings are crucial for the performance of RRD (Blanke and Christensen, 1993). Sea trials and system identification revealed that dynamic uncertainty was certainly larger than anticipated, and a model of the uncertainty was obtained (Blanke, 1996). This new knowledge is being used in subsequent control-theoretic work.

The RRD problem had earlier been formulated as a multi-objective optimization problem in an H_∞ setting. A theoretic solution had been obtained where it was shown that roll damping and yaw control could be separated if a Jula-Kucera parametrization was used (Stoustrup et al., 1994). In the reporting period, this result was extended by including the above uncertainty model in the design to obtain a truly robust design.

Work in the reporting period has also included collaboration with visitors. We used H_∞ theory for optimal roll control with Mr. Chengen Yang from Dalian Maritime University (Yang and Blanke, 1997). Mr. Gerald Hearns from University of Strathclyde investigated the applicability of quantitative feedback techniques (QFT) to obtain robust solutions. A container ship model was used for these studies.

RRD Modelling for Control

On the modelling side, a collaboration with the Danish Maritime Institute and Maersk enabled modelling and analysis of steering and roll properties for a large container ship. The complete model includes wave and wind responses and full-scale trial results for verification and adjustment of model tank parameters (Blanke and Jensen, 1997).

Collaboration with visiting Prof. Antonio Tiano from University of Pavia resulted in a detailed study about identification methods applicable to non-linear steering-roll models (Tiano and Blanke, 1997). Another result was a tutorial overview of RRD modelling (Tiano et al., 1996).

Publications: [6.2.10], [6.2.1], [6.3.45] and [6.3.40]

3.26 ATOMOS II

Researchers: Mogens Blanke, Jens Dalsgaard Nielsen, Roozbeh Izadi-Zamanabadi, Ole Borch, Tako Freerk Lootsma, Mikkel Hede

ATOMOS II (a continuation of project ATOMOS) comes under area 6.3.3 of the Waterborne Transport research (4thFramework Programme) and covers Tasks 24 and 25 of this area.

The scope of ATOMOS II is to enhance maritime safety and efficiency by combining a serious evaluation of user needs with the solid technology development skills of European marine automation companies.

The project started early 1996 and is scheduled to end by the end of 1998.

In order to achieve a demonstrable improvement in European maritime safety and efficiency the project has two objectives:

- The first objective is to develop a conceptual standard for a Ship Control Centre (HMI) working environment including the corresponding Human Machine Interface (HMI) which enhances safety and efficiency through improved operator comfort, workload and awareness, screen presentation and other relevant factors. The design of the ATOMOS II SCC shall take full account of human capabilities, limitations and performance limits as its constraints. Advanced information processing shall be developed to enhance the capabilities of the user to achieve greater safety and efficiency.

- The second objective is to enhance maritime operational safety and efficiency through an improvement of ship-borne command, control, alarm and information systems as much as practically possible, taking cost-benefit issues into account. The objective is to be achieved through design, implementation and subsequent validation of a conceptual standard for a safe, efficient and open ISC system, which allows cost-effective interoperability and interconnection between system modules from different suppliers. In order to facilitate interoperability ATOMOS

II shall define a harmonised user interface and provide a standardised process network.

Department of Control Engineering is participating in the following packages:

- Task 2.1 Architecture and Reference Model of ISC systems
- Task 2.2 Data Distribution System Onboard Ships
- Task 2.6 Sensor Information Fusion to Enhance Safety

Task 2.1 Architecture and Reference Model of ISC systems
The key objectives of this task cover a study of related application areas described in ISO, IEC and other standardisation documents, the specification and implementation of a suitable reference model for the complete ISC system, the definition of conformance standards for smooth integration of equipment on different functional levels (e.g. pumps, engines) and the description of a reliable integration mechanism access for on-board integration of additional equipment.

Results: [6.3.16]

Task 2.2 Data Distribution System Onboard Ships
The objectives of this task are to utilise and expand the results from ATOMOS to cover the entire area of ISC applications aboard ships. The integrated information system that will be the result of this work is the means needed to achieve the total integration of true ISC applications as well as external non real-time applications' demand information from the ISC system and supplying information, e.g. logistics and cargo information, back into the ISC system. To develop the necessary set of conformance classes covering the applications and components part of the ISC system.

Results: [6.3.16], [6.3.24], [6.8.9], [6.8.11] and [6.8.13],

Task 2.3 Unified Platforms and HMI
The key issue of this task is to define general requirements for the unified development platform for the ATOMOS II project, and on that basis to select development tools, operating systems, protocols, interfaceces and necessary computer elements, which to the highest possible extent will form a basis for the development work of the project.

A key element for integration is the HMI, therefore the general frame for the bridge HMI system will be implemented as a prototype toolset.

Results: [6.8.14]

Task 2.6: Sensor Information Fusion to Enhance Safety
The overall purpose of this task is to increase ship safety by preventing sensor faults from developing into failures or emergencies. More specific purposes are increased availability of machinery and process subsystems, increased dependability of sensor information presented to operators and avoidance of malfunction or unexpected shut down of machinery due to simple sensor faults. In addition to enhanced safety, automatic fault detection should ease the maintenance of complex processes and instrumentation.

Results: [6.3.12], [6.3.30], [6.5.3], [6.5.4] [6.5.7], [6.5.7] and [6.5.9]

3.27 DISC

Researcher: Jens Dalsgaard Nielsen

By standardising ISC, the risk of a compromised transport safety is reduced, since the integration of systems will be better defined, easier to accomplish and hence less error prone than is considered to be the case today. In order to support the goal of a standard, the DISC Consortium has been formed under the co-ordination of Scandlines A/S (the marketing name of DSB REDERI A/S) as a joint venture between four major contributors to the European ISC research: The ATOMOS III Consortium, The MiTS Consortium, The COMFORT Consortium and The MBB II Consortium

These consortia collectively represent the two most important European R&D consortia on Integrated Ship Control (ATOMOS III and MiTS). The most important European R&D consortium on VTMIS (COMFORT). The only European R&D consortium on maritime black box technology (MBB II). Most of the major European manufacturers of shipboard automation and navigation equipment, research institutes and Classification Societies, in combination with market importance and influence sufficient to suggest and implement European

Standards in the field. 29 European partners from 13 countries in Europe (all EU member states except Austria, Luxembourg and Belgium, including Norway), who are aggressively pursuing the common goals of DISC, are represented in the consortium. Of these, the four Consortium Co-ordinators (Scandlines A/S (DK), SINTEF (N), ISSUS (D) & DASSAULT ELETRONIQUE (F)) would serve as Contractors, and the rest of the consortia members as Associated Contractors.

The DISC Consortium is the only European Consortium that attempts to integrate all of the above technologies into a seamless, coherent system. Further, to our knowledge, a consortium of such composition and scope is unprecedented in European Waterborne Research and Development.

3.28 Structured program development

Researchers: Ole Borch and Per Printz Madsen

At the university a method for object oriented analysis and design (OOA and OOD) has been developed and is used wide spread in projects and research. The implementation is left over to the user, and often the design architecture is not recognised in the software.

Porting the design to the programmer is easier by using the Java language and a kind of structured programming beyond the object oriented

The group has developed a software structure called JDEV (Java DEVice) which fits to the OOD method and is useful in a control environment including distributed systems. JDEV is a device holding the OOD architecture formed as Java inner classes. Many JDEV's may assign to an application JDEV and everyone may communicate with each other. The advantage is that a JDEV is re-usable, easy to inherit and easy to maintain both on code level and from OOD level.

Activities:

- M.Sc. project named: A different concept for building distributed control systems. This project emphasises development of the JDEV abstraction including description of functionality, GUI and communication.
- B.Sc. project named: JDEV- Practical use of the JDEV concept. This project manly deals with a practical implementation of the JDEV concept for making process control.
- Pilot project for image selection and assignment of description is made by using the Jdev method.

The group is planning:

- A pilot project making a simple and real control system by using the Jdev on top of the OOD method.
- A graphical tool to create a collection of Jdev for a control system based on the OOD design document.

Publications: [6.7.2]

3.29 Piezo electric actuator systems

Researchers: Jan Helbo, Nordin Elghouti, Rafal Wisniewski, Mogens Blanke

The objective of this project is to enhance the use of conventional AC- and DC-motors with the special Piezo-electric motor type.

Piezo ceramic torquers can physically better be compared to a large washer than with traditional motor devices. The piezo motors does not even need a shaft to transfer its torque between two mechanical components. This gives design for servo-mechanisms and multi body units a quite new perspective and freedom in mechanical design. On the other hand, the resonance of the torquer disk, which are crucial for the control properties and the total efficiency, depend largely on the mechanical impedance which the torquer looks into. This makes it necessary to make a totally integrated design of the mechanical parts, the torquer discs and the control system. Damping associated with resonance in the disc and the remaining structure are nonlinear and depend on partly unknown properties of e.g. rubber materials between the two parts of the torquer discs. Therefore, a combined theoretical and experimental approach is needed. Unconventional ideas for constructions of joints are envisaged to fully utilise the compact shape and low weight of the piezo torquers.

Piezoelectric motors are very attractive due to their intrinsic high precision performance, power efficiency, and low weight. During the reporting period the work on piezoelectric motors has been limited to applications where large power effect is not necessary. However, recent development of technology has provided a new powerful motor giving potentials for space applications. A typical piezoelectric motor consists of three parts: the stator, the rotor, and the control system.

The objective is to design a prototype of a piezoelectric motor. Therefore, simulation environments are created and laboratory facilities are established.

3.30 Fault-tolerant Control Systems (FALCON)

Researchers: Mogens Blanke, Ole Borch, Per Brath (Danfoss and AAU), Tako F. Lootsma, Henrik Rasmussen, Claus Thybo (Danfoss and AAU)

Industrial systems for manufacture, public transportation and supply undergo a rapid transition to rely increasingly on remote control and operation, automatic sequencing, and continuously optimising controls. Information technology is contributing to a steady acceleration of features offered, but dealing with physical systems and their interfaces, faults have often lead to irregularities, accidents and even causalities. This is not acceptable with the level of safety and environment protection we desire. Statistics from the former DSB Ferries show that 40% of on-board caused irregularities were due to faults into monitoring, automation and interface to physical systems. With increasing automation, such problems become more visible. A general problem has been that fault conditions could not be treated as an integrated part of system design.

Objectives

It is the objective that solutions should be operational on genuine industrial problems and that fault tolerant design should be tested and verified on full size problems. It is the aim that this research shall be experimentally driven and in parallel develops the necessary theory. The purpose is to keep industrial applicability in constant focus.

Scope

This research effort aims at autonomous, robust fault handling for both linear and non-linear systems. A software tool to support design of autonomous fault handling in automation systems should be developed. The tool should support realisation of FTC as a supervisor level above usual control. Solutions should be operational for genuine industrial systems and performance tested on pilot or full size applications.

Approach

The approach is experimental science combined with theoretic development. Benchmarking supports a part of the development. Autonomous fault detection and fault handling will be viewed as inherent parts of control system architecture and the underlying software. The first draft of a coherent methodology was developed in the RRELCO activity, and theoretical results are available in confined areas. These results will be a basis for further development. International orientation will be maintained through the COSY research network in fault tolerant control. Applicability will be kept in focus through close collaboration with industry.

A prototype software tool will be constructed to support fault propagation analysis, fault condition simulation and implementation of fault accommodation.

Fault detection is a basic and crucial building block for all fault tolerant control. Fault detection methods will be studied for non-linear systems where results are sparse.

3.31 Reliability and Robustness in Industrial Process Control (RRELCO)

Researchers: Palle Andersen, Mogens Blanke, Søren Abildsten Bøgh, Roozbeh Izadi-Zamanabadi, Torben Knudsen, Jakob Stoustrup and Steen Tøffner-Clausen

The Danish Research Council supported the research programme with status as a National Centre for Informatics Research. A team from AAU and The Technical University of Denmark (DTU) with Professor Mogens Blanke as programme manager carried out the research effort. Funding in the reporting period was 3.7 mio Dkr.

The research programme aimed to develop existing theory and methodology for control systems design to obtain reliable and robust solutions. This means controllers that are robust over the entire envelope of normal operation of a plant and reliable such that reactions are predictable and specified when faults occur.

One programme objective was to develop the theory of robust control in a direction of enhanced applicability. A specific goal was that industrial control requirements and plant specific uncertainties should become explicit parameters of a design. To achieve this, techniques for uncertainty estimation have been enhanced. Furthermore, mixed criteria optimisation was studied, and extensions made to the new area of linear matrix inequality (LMI) techniques. Finally, inspired by the rudder-roll application, a new multi-objective optimisation theory was developed within the robust control framework where output sensitivity specifications can be achieved independently for each output for systems with a single input, multi-output structure. This new result was later generalised to multi-input multi-output systems.

A second objective was to improve control system reliability. The basic idea was to extend controllers with a meta-layer that conducts autonomous fault detection and accommodation. The first activity was to look at fault propagation. A new analysis method was proposed. It is based on a matrix formulation using a Boolean algebra. It features easy determination of end effects of faults and gives locations where reconfiguration could be implemented. A method for systematic development was formulated and applied to the Ørsted satellite project. The logic within supervisory control was studied to obtain a complete and correct implementation. Software architecture based on computational reflection was proposed and experience obtained in an EU project. Furthermore, existing techniques in fault detection and isolation were robustified. In the course of development, this new area has been defined as Fault-tolerant Control (FTC).

Three industrial applications were used as examples to get genuine experience and refinement of research results. In rudder roll damping for ships where the multi-objective output sensitivity problem was first recognised. In wind turbine control where uncertainty identification and robust control were tested on a 500 kW turbine. In attitude control for the ØRSTED satellite fault-tolerant principles were applied. The result is that autonomous operation of the satellite has been achieved for most of the foreseeable fault conditions.

The programme has been a catalyst for intensive international and national research collaboration. Essential industries have decided support the development within the application areas. The group participated in two European networks. One is in robust and adaptive control (EURACO) co-ordinated by Strathclyde University. The other (COSY) has fault-tolerant control, as one of its themes with 17 groups as members. This theme is co-ordinated from Aalborg University.

In addition to intensive international publication, the programme has resulted in industry specific research aiming at possible later implementation. Fault-tolerant control for inverted drives for induction motors (Danfoss Drives A/S) is one activity, development of robust control for the new DVD drives is another (B&O A/S). Specific results of the project are incorporated in other descriptions of research activities. Research results have been very well accepted by peers in international research and by industry. Publications in 1996/1997:

- 1 book, 2 Ph.D. theses, 1 book chapter
- 11 papers in international journals
- 30 papers in proceedings from international conferences
- 6 invited lectures

4. RESEARCH NETWORKS

4.1 The EURACO network

The Department participates in the EURACO network (Robust and Adaptive Control) (1993-97). The network has had one annual course/workshop where the members of the network, and young researchers were gathered for one week. These events have had a noticeable stimulation on the progress and international orientation of the Ph.D. students' activities. EU funding of the network provided travel grants for meetings.

4.2 The COSY Network

The Department participates in a project funded by the European Science Foundation: Control of Complex Systems (COSY). The COSY programme has four main themes. Theme 2 is on Fault-tolerant Control of Complex Systems. This theme is co-ordinated by Mogens Blanke. The theme has 17 European groups as members (end 1997). The activity has resulted in close collaboration with several of these groups. One activity has been arranging research visits from one to four weeks duration, another is exchange of Ph.D. students for longer duration. One Ph.D. student from Aalborg visited Univ. of Lille for 4 months in 1997, another will be visiting Coventry Univ. for 6 months in 1998. In Aalborg, we have had shorter visits from TU of Hamburg-Harburg (D), Univ. of Valencia (Esp), Univ. of Coventry (UK), Southampton Univ. (UK) and IST (P).

4.3 ERASMUS

In the period the Department headed as co-ordinator in a joint student mobility programme between University of Hull (UK), University of York (UK), Gerhard-Mercator Universität Gesamthochschule, Duisburg (D), Ecole Nationale Superieure de Valencia (Esp). 7 students have studied abroad and the Department has hosted 5 students.

5. PH.D. THESES

Søren Abildsten Bøgh: Fault Tolerant Control Systems - a Development Method and Real-Life Case Study. December 1997. Doc. No. D97-4198

This thesis considers the development of fault tolerant control systems for the category of automated processes that do not necessarily comprise a high number of identical sensors and actuators to maintain safe operation, but still have a potential to improve immunity to component failures. Increased availability for these control loops is achieved by designing the control system to perform on-line detection and reconfiguration in case of faults before the safety system makes a close-down of the process.

A general development methodology is given in the thesis that carries the control system designer through the steps necessary to consider fault handling in an early design phase. This methodology covers the analysis, design, and implementation of fault tolerant control systems on an overall level.

Two application case studies are used to emphasise practical aspects. One is an electro-mechanical actuator in a position control loop for a diesel engine speed governor, where the purpose is to avoid a total close-down in case of the most likely faults. The second is a fault tolerant attitude control system for a micro satellite where the operation of the system is mission critical. The purpose is to avoid hazardous effects from faults and maintain operation if possible.

The main contributions of the thesis are:

- A simple technique for modelling component faults propagation to end-effects on system level,
- A method for handling feedback loops in the fault propagation analysis,
- A detailed study on design of supervisory systems for the decision taking in fault handling,
- A method for verifying correct operation of the supervisor based on a completeness check against the fault propagation analysis.
- A comparative study on fault detection and isolation algorithms applied to the diesel engine speed governor,

The usage of software tools to support the development process is Illustrated with an off-the-shelf product for constraint logic solving and state-event machine analysis.

Experience from this study highlights requirements for a dedicated software environment for fault tolerant control systems design.

Jan H. Mortensen: Control Strategy for Improvement of the Load Following Capability of Power Plant Units. December 1997. Doc. No. D97-4199.

The capability of performing fast load changes has been an important issue in the power market and will become increasingly more so due to the commercialisation tendencies on the European power market. An optimising control system for improving the load following capability of power plant units has therefore been developed. The system is implemented as a complement producing additive control signals to the existing boiler control system, a concept which has various practical advantages in terms of implementation and commissioning. The optimising control system takes into account the multivariable and load dependent non-linear characteristics of the boiler process as a scheduled LQG-controller with feedforward action is utilised. Two different methods for scheduling an LQG-controller have been tested, parameter scheduling and scheduling on control signals. The LQG-controller improves the control of critical process variables making it possible to increase the load following capability of a specific plant. Field tests on a 265 MW coal fired power plant unit reveals that the maximum allowable load gradient, which the plant can be imposed to, can be increased from 4 MW/min. to 8 MW/min.

Rafal Wisniewski: Satellite Attitude Control Using Only Electromagnetic Actuation. December 1996. Doc. No. D97-4168

The primary purpose of this work was to develop control laws for three axis stabilisation of a magnetic actuated satellite. This was achieved by a combination of linear and non-linear system theory. In order to reach this goal new theoretical results were produced in both fields. The focus of the work was on the class of periodic systems reflecting orbital motion of the satellite. In addition to a theoretical treatment, the thesis contains a large portion of application considerations. The controllers developed were implemented for the Danish Ørsted satellite.

The control concept considered was that interaction between the Earth's magnetic field and a magnetic field generated by a set of coils in the satellite can be used for actuation. Magnetic torquing was found attractive for generation of control torques on small satellites, since magnetic control systems are relatively lightweight, require low power and are inexpensive. However, this principle is inherently non-linear and difficult to use, because control torques can only be generated perpendicular to the geomagnetic field vector. So far, this has prevented control in all three axes using magnetorquers only.

A fact that the geomagnetic field changed periodically when a satellite is on a near polar low Earth orbit was used throughout this thesis. Confined computer capacity and a limit on electrical power supply were separate obstacles. They demanded computational simplicity and power optimality from the attitude control system. The design of quasi-optimal controllers for a real-time implementation was a subject of considerations in the part on linear control methods for a satellite with a gravity gradient boom. Both time varying and constant gain controllers were developed and their performance was tested via simulation.

The nonlinear controller for a satellite without appendages was given in the second part of the thesis. Its design was based on sliding mode control theory. The essence of the sliding control presented in the thesis was to split the controller design into two steps: a sliding manifold design and a sliding condition design. The emphasis was on the sliding condition design, which was stated as a continuous function of the state. A control law for magnetic actuated satellite was proposed.

Complete comprehension of the nature of the satellite control problem required a new approach merging the nonlinear control theory with physics of the rigid body motion and an extension of earlier results in this field using the theory of periodic systems. The Lyapunov stability theory was employed based on the potential and kinetic energy of the rigid satellite. A velocity controller that contributes to dissipation of both kinetic and potential energy was proposed. The velocity control was shown to provide four stable equilibria, one of which was the desired orientation. It was explained how the equilibria depended on the ratio of the satellite's moments of inertia. It was further investigated how to control the attitude, such that the satellite was globally asymptotically stable in the desired orientation, avoiding the undesired equilibria.

The main contribution of this work was to show that three-axis control can be achieved with magnetorquers as sole actuators in a low Earth orbit. A rigorous stability analysis was presented, and detailed simulation results showed convincing performance over the entire envelope of operation of the Danish Ørsted satellite.

6. PUBLICATIONS

6.1 Books and Book Contributions

[6.1.1] Knudsen M., Jensen J.G., Julskjær V., Rubak P. *Determination of Loudspeaker driver Parameters Using a System Identification Technique*. An anthology on articles on loudspeakers. Audio Engineering Society. Volume 4. Pages 422-430. July 1996.

[6.1.2] Kofoed L.B., Rosenørn T.U., and Jensen L.P. *Participation, Learning and Technological Changes.* A contribution to "Working Environment & Technological Development". RUC. Tek. Samf. Forlaget. (March 1997).

[6.1.3] Tøffner-Clausen S. System Identification and Robust Control - A Case Study Approach. Springer. May 1996

6.2 Journal Articles

[6.2.1] Blanke M. and Jensen A.G. Dynamic Properties of Container Vessel with Low Metacentric Height. Transaction of the Institute of Measurement and Control. Volume 19(2) Pages 78-93.1997.

[6.2.2] Blanke M. *Consistent Design of Dependable Control Systems*. Control Engineering Practice. Volume 9. Pages 1305-1312. September 1996.

[6.2.3] Blanke M., Izadi-Zamanabadi R., Bøgh S.A., Lunau C. *Fault Tolerant Control Systems - A Holistic View*. Control Engineering Practice. Volume 5. Number 5. Pages 693-702. May 1997.

[6.2.4] Knudsen T. Optimal Calculation of Residuals for ARMAX Models with Applications to Model Verification. European Journal of Control. Volume 3. Number 3 Pages 235-246. (1997).

[6.2.5] Schiøler H., Kulczycki P. *Neural Network for Estimating Conditional Distributions*. IEEE trans. on Neural Networks Vol. 8, No. 5, Sept 1997.

[6.2.6] Shafai B., Beale S., Niemann H.H., Stoustrup J. *LTR Design of Discrete-time Proportional-Integral Observers*. IEEE Transactions on Automatic Control. Pages 1056-1062. 1996.

[6.2.7] Stoustrup J. and Niemann H.H. *Multiobjective Control for Multivariable Systems with Mixed-sensitivity Specifications*. International Journal of Control. Volume 66(2). Pages 225-243. 1997.

[6.2.8] Stoustrup J., Grimble M.J., and Niemann H.H. *Design of Integrated Systems for the Control and Detection of Actuator/Sensor Faults*. Sensor Review. Volume 17(2). Pages 157-168. 1997.

[6.2.9] Sørensen O. *Non-linear Pole-placement Control with a Neural Network*. European Journal of Control (1996) 2. Pages 36-43.

[6.2.10] Tiano A. and Blanke M. *Multivariable Identification of Ship Steering and Roll Motions*. Transaction of the Institute of Measurement and Control. Volume 19(2) Pages 63-77.1997.

[6.2.11] Zhao K.-Y. and Stoustrup J. Computation of the Maximal Robust H-2 Performance Radius for Uncertain Discrete Time Systems with Nonlinear Parametric Uncertainties. International Journal of Control. Volume 64. 1997.

6.3 Conference Contributions

[6.3.1] Bak T. and Wisniewski R. *Passive Aerodynamic Stabilization of a Low Earth Orbit Satellite*. Proceedings of 3rd ESA International Conference on Spacecraft Guidance, Navigation and Control Systems, Noordwijk, November 1996.

[6.3.2] Bak T. *Onboard Attitude Determination for a Small Satellite*. Proceedings of 3rd ESA International Conference on Spacecraft Guidance, Navigation and Control Systems, Noordwijk, 28-28 November, 1996.

[6.3.3] Bak T., Wisniewski R., and Blanke M. *Autonomous Attitude Determination and Control System for the Ørsted Satellite*. Proceedings of the 1996 IEEE Aerospace Applications Conference, Snowmass at Aspen, Colorado February 3-10 1996. Volume 2. Pages 173-186.

[6.3.4] Blanke M. *A Component Based Approach to Industrial Fault Detection and Accommodation.* Preprints of 13th World Congress of IFAC International Federation of Automatic Control, San Francisco June 30-July 5, 1996. Volume N. Pages 97-102.

[6.3.5] Blanke M. Fault Tolerant Control System Design Using Automated Methods from Risk Analysis. SRDA technical symposium. Warrington, UK, Feb. 1996.

[6.3.6] Blanke M. *Uncertainty Models for Rudder-Roll Damping Control*. Preprints of 13th World Congress of IFAC International Federation of Automatic Control, San Francisco June 30-July 5, 1996. Volume Q. Pages 285-290.

[6.3.7] Breslin S.G., Tøffner-Clausen S., Grimble M.J., and Andersen P. *Robust Control of an Ill-Conditioned Aircraft*. Preprints of 13th World Congress of IFAC International Federation of Automatic Control, San Francisco June 30-July 5, 1996. Volume P. Pages 213-224.

[6.3.8] Bøgh S.A. and Blanke M. *Fault-Tolerant Control - A Case Study of the Ørsted Satellite*. Proceedings of Fault Diagnosis in Process Systems. Colloquium in York, April, '97.

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[6.3.10] Cromme M. and Stoustrup J. *Semi-global H-infinity State Feedback Control*. Proceedings of the Proceedings of the European Control Conference, July 1997.

[6.3.11] Hangstrup M., Ordys A.W., and Grimble M.J. *Dynamic Algorithm for LQGPC Predictive Control*. Proceedings of the MMAR '97 Conference. (October 1997).

[6.3.12] Izadi-Zamanabadi R. and Blanke M. *A Ship Propulsion System as a Benchmark for Fault-Tolerant Control*. Proceedings of IFAC Safeprocess '97, August 1997, Hull, UK.

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[6.3.14] Jensen L.P., Kofoed L.B. *Focusing the Working Environment During Organizational Changes in the Processing Industry*. Sixth European Conference on Cognitive Science Approaches to Process Control. Pages 137-139. (September 1997).

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[6.3.16] Jørgensen N. and Nielsen J.D. *Trends in Integrated Ship Control Networking*. Proceedings of the 14th IFAC Workshop on Distributed Computer Control Systems, July '97, Seoul, Korea. Pages 139-144.

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[6.3.20] Knudsen T. *The Initialization Problem in Parameter Estimating for General SISO Models*. Preprints of 13th World Congress of IFAC International Federation of Automatic Control, San Francisco June 30-July 5, 1996. Volume J. Pages 221-226.

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6.4 Preprint

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6.5 Research Reports

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[6.5.2] Bak T., Blanke M., and Wisniewski R. *Study on Geomagnetic Space Observatories.* (July 1996).

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[6.5.10] Yang C. A Robust RRD Controller For a Container Vessel. (April 1997).

6.6 Ph.D. Theses

[6.6.1] Bidstrup N. Robust Adaptive Speed Control of Induction Motor Drives. (July 1993).

[6.6.2] Bøgh S.A. Fault Tolerant Control Systems - a Development Method and Real-Life Case Study. (December 1997).

[6.6.3] Børsting H. Robust Parameter - and Signal Estimation in Induction Motor. (September 1993).

[6.6.4] Drejer N. Methods of Run-Time Error Detection in Distributed Process Control Software. (May 1994).

[6.6.5] Hansen T. Procesoptimerende multivariable regulatorer til kraftværkskedler. Process Optimizing Multivariable Controllers for Powerplant Boilers. (October 1993).

[6.6.6] Jørgensen R.B. Development and Test of Methods for Fault Detection and Isolation. (August 1995).

[6.6.7] Knudsen M. Estimation of Physical Parameters in Linear and Nonlinear Dynamic Systems. (January 1993).

[6.6.8] Kristensen C.H. A Formal Approach to Run-Time Evaluation of Real-Time Behaviour in Distributed Process Control Systems. (December 1994).

[6.6.9] Madsen P.P. Neurale Netværk anvendt indenfor Proceskontrol. Neural Network for Process Control. (Marts 1993).

[6.6.10] Mortensen J.H. Kontrolstrategi til frigørelse af kraftværkers reguleringsevne. (December 1997).

[6.6.11] Nielsen K.M. and Nielsen J.D. Metoder for Modellering, Simulering og Regulering af Større Termiske Processer anvendt I Sukkerproduktion. Methods for Modelling, Simulation and Control of Large Scale Thermal Systems Applied in Sugar Production. (January 1992).

[6.6.12] Rasmussen H. Self-tuning Torque Control of Induction Motors for High Performance Applications. (December 1995).

[6.6.13] Schiøler H. Part 1. Ulineær Regression med Neurale Netværk. Nonlinear Regression using Neural Network. Part 2. Prediktion, Simulering og Regulering med Neurale Netværk. Prediction, Simulation and Control using Neural Network. (February 1993).

[6.6.14] Sørensen O. Neural Networks in Control Applications. (October 1994).

[6.6.15] Tøffner-Clausen S. System Identification and Robust Control - A Synergistic Approach. (October 1995).

[6.6.16] Wisniewski R. Satellite Attitude Control Using Only Electromagnetic Actuation. (March 1997).

6.7 Lecture Notes

[6.7.1] Andersen P., Pedersen T.S., and Tøffner-Clausen S. *Dynamiske Modeller af Termiske Systemer*. (January 1996).

[6.7.2] Borch O. HOW TO DO - 1. Programming I/O with Java Native Interface. (December 1997).

[6.7.3] Kristensen C.H. *Kommunikationssimulator*. (February 1996).

[6.7.4] Kristensen C.H. and Rasmussen B. Objektorienteret Analyse og Design anvendt Proceskontrolsystemer. (June 1996).

6.8 Technical Memoranda (Internal Reports)

[6.8.1] Bak T. Ørsted Integration Test Procedure, Ørsted/TN317, ver. 0.1. (March 1996).

[6.8.2] Bøgh S.A. *ACS Benchmarking*. (June 1996).

[6.8.3] Bøgh S.A. ACS Flight SW EM Setup Integration Test Report. (June 1996).

[6.8.4] Bøgh S.A. ACS Flight SW FM Setup Integration. Test Report. (January 1997).

[6.8.5] Bøgh S.A. ACS S/W Integration First Test Results. (March 1996).

[6.8.6] Bøgh S.A. *ACS Test at IABG*. (June 1997).

[6.8.7] Bøgh S.A. Flight Operation Procedures for ACS. (October 1996).

[6.8.8] Bøgh S.A. *Ørsted Prism Alignment*. (January 1997).

[6.8.9] Hede M. and Nielsen J.D. Network Management System - System Requirements Specification – Preliminary. (June 1996).

[6.8.10] Knudsen M. and Kjær J.N. Manual for produktion af Computer Based Instruction med Medi8or. (May 1997).

[6.8.11] Knudsen M. *Sensor Tools Manual*. (September 1996).

[6.8.12] Nielsen J.D. and Hede M. *Communication Pattern Analysis*. (December 1996).

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6.9 Miscellaneous

[6.9.1] Blanke M. *Reliable Control Systems - Systematic Methods for Fault Handling Design*. Final Report for STVF project grant no.16-4979. (September 1996).

[6.9.2] Helbo J. and Drescher K. *Activity Report 1994-1995*. (1996).

[6.9.3] Helbo J., Østergaard J., and Drescher K. *Research Evaluation*. (January 1997).

7. COURSES

The teaching at all levels at Aalborg University differs from the traditional lecture form and organization in subjects. Instead the pedagogical concept is problem-centred and project-organized studies. Problem-centered study means that the students will acquaint with and understand professional theories in connection with solution of concrete problems. Theories and methods are learned through their practical use. This form of study provides a professional training under working conditions similar to those encountered in employment and thereby it has a greater degree of relevance to the student.

The courses deal with the theoretical and professional contents of a "theme". Each course is normally divided into 6 lectures, each with a duration of half a day. This means that minimum pedagogical unit is half a day, morning or afternoon. Half of the courses are generel in nature, the other half are project-oriented in order to support the students in the project work.

7.1 Bachelor Courses

Application Specific System Architecture. This course gives an introduction to the basic terms and methods in industrial computer systems. The main topics are PLC's, distributed process controllers and man machine interface. 12 participants. Lecturer: Per Printz Madsen.

Basis Programmes. This course is an introduction to operating systems, including processes, memory management, file systems, device drivers and networking. 12 participants. Lecturer: Per Printz Madsen.

C++ Programming. Hands on course. 135 students. Lecturer: Ole Borch

Circuit Theory. To provide methods of analysing linear electric circuits, including analysing of stationary and transient phenomena. 130 participants. Lecturer: Jørgen Østergaard

Communication in process control systems. The course introduces realtime communication and network standards used in control systems. 18 participants. Lecturer: Niels Jørgensen.

Computer Networks. Basic theory and methods for computer network, architectures and models are taught. 40 students. Lecturer: Ole Borch

Control Engineering. To acquaint students with both classical and modern methods which are used in design of analog and digital control systems. 18 participants. Lecturers: Morten Knudsen

Control Engineering. To acquaint students with both classical and modern methods which are used in design of analog and digital control systems. 16 participants. Lecturers: Tom Søndergaard Pedersen, Palle Andersen.

Control of chemical and biochemical plants. To give basic principles of sequence control and feedback control and give skills in application in designing and tuning of P, PI, and PID controllers. 35 participants. Lecturers: Kirsten Mølgaard Nielsen, Tom Søndergaard Pedersen, Palle Andersen.

C-programming, algorithms and data structures. The C programming language. Fundamental algorithms and data structures. Recursion. Trees. I/O. Software environments. 90 participants. Lecturers : John Nørgaard Nielsen and Kristian G. Olesen.

Data collection using PC. An introduction to basic sampling theory, A/D and D/A convertion and data collection via a I/O board and a PC. 35 participants. Lecturers: Kirsten Mølgaard Nielsen, Palle Andersen

Data Intensive Systems. Information structure. Data flow and data processing. Data reduction. Persistence. Security and integrity. Introduction to object oriented programming and databases. 25 participants. Lecturer: John Nørgaard Nielsen.

Databases. Logical and physical database. Entity-relationship models. Relational algebra and databases. Design. Queries. Integrity and security. The physical database. 12 participants. Lecturer: John Nørgaard Nielsen.

Design and Analysis of Algorithms and Datastructures. Fundamentals. Complexity. Trees. Recursion. Searching and sorting. Graph algorithms. Turing machines. Church's thesis. Computability. P and NP classes. 12 participants. Lecturer: John Nørgaard Nielsen.

Digital Control. To inform about methods and software for digital simulation and control of linear and nonlinear systems. 42 participants. Lecturer: Ole Sørensen.

Discrete-Time Systems. To provide a knowledge of the theoretical basis for calculations regarding the dynamic behaviour of linear discrete-time systems. 120 participants. Lecturer: Jan Helbo.

Feedback Theory I. To give basic knowledge on feedback theory and its application in electronic amplifiers. Effect of feedback on parameter variations, noise, frequency response and stability. 100 participants. Lecturer: Palle Andersen.

Feedback Theory II. To give basic knowledge of feedback theory. Time and frequency domain analysis. Steady state tracking. Stability. 85 + 35 participants. Lecturer: Tom Søndergaard Pedersen.

How to study in groups making projects. A course for first year students, helping them to a new way of studying. The elements are: Problemorientation, learning processes, project management, questionnaire's - interview's etc., communication - presentation and documentation, co-operation in groups - group processes. 120 participants. Lecturer: Lars Peter Jensen.

Internet programming. The course introduces the Internet, the protocols and socket programming. A brief introduction to client-server implementation is also given. 30 participants. Lecturer: Niels Jørgensen.

Introduction to Feedback Theory. To give the basic principles of feedback control especially design and tuning of P, PI and PID controllers. 35 participants. Lecturers Kirsten Mølgaard Nielsen, Palle Andersen

Introduction to MatLab A brief introduction to the mathematical programming language MatLab, covering basic syntax, simple programming structures (such as functions and M-files) and examples from engineering practice.10 participants. Lecturer: Jan Dimon Bendtsen.

Introduction to Matlab. To give an introduction to data processing and presentation with Matlab. 35 + 25 + 100 participants. Lecturers: Tom Søndergaard Pedersen and Palle Andersen.

Linear System Theory. Modelling of linear systems. Linear differential equations. Laplace-transformation. 130 participants. Lecturer: Jørgen Østergaard.

Methods in Project Work An introduction to group project work in the technical and natural sciences, emphasising the structuring of a project report and the technical and natural scientific analysis methods. 50 participants. Lecturer: Jan Dimon Bendtsen.

Modelling and Control of Dynamic Systems. An introduction to dynamic models of mechanical, electromechanical and liquid-level systems. Classic control theory, frequency and time domain analysis. 100 participants. Lecturer: Tom Søndergaard Pedersen.

Modelling of Mechanical Systems. To learn fundamental statics with emphasis on grids and beams. Transmissions with rigid and elastic elements. Dynamics of rigid bodies. 30 participants. Lecturer: John Nørgaard Nielsen.

Object Oriented System Development with Java. Methods for analysis, design and implementation in Java. 80 students. Lecturer: Ole Borch.

Process Control Systems. To acquaint students with concepts, principles terminology and equipment used in connection with industrial automation systems. 25 participants. Lecturer: Per Printz Madsen.

Purpose driven real-time systems. Advanced real-time programming and RT scheduling theory. 30 participants. Lecturer: Jens Dalsgaard Nielsen.

Real Time Systems I. To provide an introduction to, and experience of the application of multi programming as a tool for solving complex real-time programming problems. 60 participants. Lecturer: Jens Dalsgaard Nielsen.

Simulation Techniques. To inform about methods for simulation of linear and nonlinear systems. 15 participants. Lecturer: Palle Andersen.

Statistics and Stochastic Processes I. Statistics: General introduction to point and interval estimation and test theory. Most of the classical tests are presented e.g. one and two sample normal tests, binomial test, goodness of fit test etc. **Stochastic processes**: The basic is a general description of stochastic processes e.g. ergodisity, stationarity, autocovariance and spectrum. Different kinds of processes are included in the course e.g. random walk, poisson, normal, markov etc. 90 participants. Lecturers: Torben Knudsen and (Uwe Hartmann).

System Programming. Methods and principals for programming microcomputers close to the hardware. Drivers, interrupt assembler, structure and architectures. 120 students. Lecturer: Ole Borch

System Theory. Life cycle of a technical system. Specification, design, implementation, test and documentation of complex systems. Tools for structured software development. 120 participants. Lecturer: John Nørgaard Nielsen.

7.2 Master Courses

Adaptive Control I. To provide a knowledge of the theories and methods which are applied in design of adaptive controllers. 20 participants. Lecturer: Henrik Rasmussen.

Adaptive Control II. To provide knowledge of the theories and methods which are applied in the design of adaptive controllers. 20 participants. Lecturer: Henrik Rasmussen.

Advanced Network Protocols The Internet protocol stack. World Wide Web. 30 students. Lecturer: Ole Borch

Chaos and Science. The nonlinear world. Bifuications and chaos. Introduction to fractals. Scientific implications. 6 participants. Lecturer: John Nørgaard Nielsen.

Computer Network and Protocols. Basic architectures and models. Link level protocols. HDLC, LLC, MAC. 80 students. Lecturer: Ole Borch

Digital Control and Simulation of Nonlinear Systems. To provide knowledge of the theories and methods which are applied in the design of digital control systems. To provide a basic knowledge about simulation of nonlinear dynamic systems, using Matlab. 21 participants. Lecturer: Morten Knudsen, Lars Peter Jensen.

Distributed Process Control Systems. To provide an introduction to the practical methods and techniques for the structuring of distributed control of systems. 15 participants. Lecturers: Jens Dalsgaard Nielsen and Niels Jørgensen.

Dynamic Modelling and Simulation of Thermohydraulic Systems. To introduce the dynamic modelling of thermohydraulic processes based on physical laws and apply simulation methods for systems with lumped and distributed parameters. 12 participants. Lecturer: Palle Andersen.

Java Programming Hands on course. 36 students. Lecturer: Ole Borch

Neural net in Robotic. To acquaint students how model and control Robots. Neural nets are learned for Robot unlinearities and used for identification and control. Lecturers: Jan Helbo and Ole Sørensen.

Neural Networks in Process Control. To provide knowledge of the types, methods and applications in relation to neural network for process control (identification and control). 20 participants. Lecturer: Per Printz Madsen and Ole Sørensen.

Optimal Control. To provide knowledge of theories and methods in relation to the design of optimal controllers. 40 participants. Lecturer: Ole Sørensen.

Plant Control-Oriented Operating Systems. With commencement in general techniques to master the specific demands which are made on operating systems in connection with the design and implementation of distributed control systems. 18 participants. Lecturer: Niels Jørgensen and Jens Dalsgaard Nielsen.

Robust Control. To enable the students to analyze controlled system with respect to performance and robustness. To introduce concepts like nominal and robust stability and performance both for SISO and MIMO systems. To introduce H-infinity and mu control theory. 18 participants. Lecturers: Palle Andersen and Jakob Stoustrup.

Scientific Communication. To provide the students with a knowledge and practical experience of the methods of international communication which are used by engineering graduates. 120 participants. Lecturers: Mogens Blanke and (Annelise Rosenfalck).

Safety aspects of control systems. The objective of the course is to give participants an overview of safety aspects of control systems and a working knowledge of selected methods in fault detection. The aim is that students should be able to apply these methods in their project work as well as later in their engineering career. The course includes: an overview of the design process for fault tolerant systems, introduction to construction of fail-safe systems, model based fault-detection and isolation using observer methods, detection using either threshold or cusum techniques. Lecturer: Professor Mogens Blanke.

Scientific Method. Scientific argumentation. The research process. Science and reality. Objectivity and ideology. Science, technology and ethics. 120 participants. Lecturers: John Nørgaard Nielsen and (Erik Granum).

State feedback control. To introduce concepts and methods for state space control design and observer theory. 18 partipants. Lecturer: Jakob Stoustrup

Statistics and Stochastic Processes II. Statistics: Multiple linear regression. Analysis of variance. Simulation. Stochastic Processes: Detection, estimation and filtering. 90 participants. Lecturers: Torben Knudsen and (Uwe Hartmann).

Strategic Design of Control Systems. To acquaint students with structured methods for decomposing and analysing large scale industrial processes, to enable students to design large scale control systems employing only control elements which are commercially available and to systems. 20 participants. Lecturers: Kirsten Mølgaard Nielsen and Tom Søndergaard Pedersen.

System Identification I. To provide an introduction to system identification. 90 participants. Lecturer: Torben Knudsen.

System Identification II. To provide an insight into the application of the theories and methods for system identification in particular: experiment design, model validation, and direct estimation of physical parameters. 24 participants. Lecturer: Morten Knudsen.

7.3 Ph.D. Courses

Fault detection for control and signal processing. The objective of the course is to make participants able to design systems to prevent faults in computer-based control systems to develop into failures at a plant level.

The scope of the course is detection of faults in system components of a control loop or the associated process.

The main themes covered are:

- Fault detection based on residual generation for dynamic systems,
- Analytic redundancy methods, including the parity space approach and diagnostic observers. Detection is a noisy environment is treated using statistical decision theory.
- Adaptive threshold techniques are explained. Finally,
- Hints to electronic design for interface for sensors and actuators to enable rapid detection of single sensor faults.

The audience would be researchers in research or industry, who are working with control engineering, manufacturing, power systems, communication, or general signal processing. Lecturers in 1996: Professor Mogens Blanke, AAU, Professor Ron Patton, University of Hull

System Identification and signal estimation. Experiment design and identification of continous time models. Estimation of model uncertainty due to variance of parameter and undermodelling. Extended Kalman filters and prediction error methods in recursive identification. 12 participants. Lecturers: Morten Knudsen, Steen Tøffner-Clausen, Palle Andersen, Torben Knudsen.

Robust and Optimal Control: Robust stability and performance of multivariable systems. H-2 and H-infinity optimal control. 6 participants. Lecturers: Steen Tøffner-Clausen and Palle Andersen.

Writing and Reviewing Scientific Papers. The aim is to improve the participants competence in writing and reviewing scientific papers. The course takes a practical approach and focuses on the craftsmanship needed as a scientist. It is recommended that this course is taken during the first period of a Ph.D.-study. Ph.D.-students from all institutions at the Faculty of Engineering and Science can benefit from attending the course. The discussions will address general issues related to scientific writing. The course is organised in three activities. First the students are asked to study selected literature on the subject. Second, two one-day seminars are devoted to presentations by the organisers, discussions amongst participants, and lectures by invited speakers. Third, the students are required to practice both writing and reviewing in specially designed exercises. Lecturers: Mogens Blanke and Jakob Stoustrup.

Data–Collection, Handling and Presentation on PC. This course is for Ph.D. students who are dealing with PC's for data collection, data handling, control and data presentation. To cope all these fields on a level of how to do and why, it is necessary to understand the mathematical background for sampling analogue signals and presentation of digital signals. To control a system it is necessary to be able to measure signals from transducers and to generate control signals for the actuators. Standards for transducer signals are presented and elementary control theory for generating the control signal for the actuator is examined. It is also shown and demonstrated how to measure signals from a PC using different data collection boards. How the hardware works and how it is initialised from a program is exercised. 10 participants. Lecturer: Henrik Rasmussen.

Neuro-Fuzzy Adaptive Modelling and Control. The purposes of this course are:

- To give the participants an survey of NeuroFuzzy methods.
- To describe some of the most promising neurofuzzy control methods, with the emphasis on stability and adaptation.
- To give the participants hand on experience with some of these Neurofuzzy control methods.
- To bring the participants knowledge about NeuroFuzzy to a level so they are able to participate in the international research in this area.

The contents of this course are:

- Introduction to Neural networks and Fuzzy logic.
- NeuroFuzzy systems.
- Knowledge representation and learning in NeuroFuzzy systems.
- NeuroFuzzy controllers and their applications.
- Stability and adaptation for NeuroFuzzy control systems.

8 participants. Lecturer: Henrik Schiøler

7.4 Computer aided Courses

A new challenge is computer-aided courses, of which the Department has introduced the following:

Computer based Introduction to Classical System Identification (Morten Knudsen). The course has been tested and will run from 1998

Computer based Introduction to Matlab (Morten Knudsen). The course has been tested and will run from 1998

C-programming, Algorithms and Data Structures (John Nørgaard Nielsen (and K.G.Olesen)). 70 participants at bachelor level.

Introduction to the Internet (Ole Borch and John Nørgaard Nielsen). The course has been tested and will run from 1998.

Network-based Database Course (John Nørgaard Nielsen) 10 participants at bachelor level.

8. COMPUTER RESOURCES

The computer network and the computers have in general stayed unchanged from 1995 to 1997, and the department has as before benefited from its initiative in the years before.

It is our intention to renew one quarter of our computer resources each year, the result being that on average we buy 2 multiprocessor SUN servers each year, which has been the case for this period. The same is more or less true for PC's and X-terminals. Hence at any time half of the PC's will be less than 3 years old.

The computer resources are based on a number of powerful SUN multiprocessor servers, which service the PC's and X-terminals. Each student room housing 6 to 8 students, is equipped with an X-terminal, and each staff member and Ph.D. student have their own PC and/or X-terminal. In the student group rooms, the students also have access to the Department Net via their private computers.

Currently the computer resources are:

- 1 multiprocessor SUN servers (shared with the other departments) (1 year old)
- 1 multiprocessor SUN file server (2 years old)
- 1 multiprocessor SUN server dedicated as WEB-server and WWW-Proxy (6 years old)
- 7 multiprocessor SUN servers (from 1 to 6 years old)
- 2 SUN clients (6 years old)
- 40 Tektronix X-terminals (from 5 to 7 years old)
- 40 Linux-based colour X-terminals (1 year old)
- 80 PC's with network access running Window-95 or Linux. (from 0 to 5 years old)

The network is now being upgraded to 100 Mbit whenever new equipment is acquired.