Activity Report

1998/1999

Division of Optimization and Systems Theory
Department of Mathematics
Royal Institute of Technology
SE–100 44 Stockholm, Sweden
http://www.math.kth.se/optsyst/

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The Division of Optimization and Systems Theory is part of the Department of Mathematics at the Royal Institute of Technology. This report summarizes the activities at this division during the academic year 1998/1999 (July 1998 – June 1999).

Optimization and Systems Theory is a discipline in applied mathematics primarily devoted to methods of optimization, including mathematical programming and optimal control, and systems theoretic aspects of control and signal processing. In addition, attention is given to mathematical economics and applied problems in operations research, systems engineering and control engineering.

Research performed at the Division of Optimization and Systems Theory includes various topics in *mathematical systems theory*, with particular emphasis on stochastic systems, filtering, identification and robust and nonlinear control; *mathematical programming*, with emphasis on nondifferentiable optimization, large-scale nonlinear programming, dual optimization methods, structural optimization, and a wide range of applications; *systems engineering*; and *mathematical economics*. The division also has an Optimization Laboratory devoted to collecting state-of-the-art optimization routines, making them available to research institutions and industry. The division is also one of four core groups in the Center for Autonomous Systems, a research consortium supported by a grant from the Strategic Research Foundation.

The Division of Optimization and Systems Theory offers undergraduate courses in mathematical programming, mathematical systems theory, optimal control and mathematical economics, as well as various topics in operations research and modeling. There is an extensive graduate program.

A regular *Optimization and Systems Theory Seminar* has been running weekly. In addition, more tutorial and informal seminars in mathematical programming and systems and control have been running in parallel.

Contents

1 Personnel

1.1 List of personnel

Professor (Professor)

Anders Lindquist, TeknD

Docenter (Associate professors)

Anders Forsgren, TeknD, universitetslektor
Xiaoming Hu, PhD, forskare
Krister Svanberg, TeknD, universitetslektor Director of undergraduate studies

Universitetslektor (Senior lecturer)

Ulf Brännlund, TeknD
Claes Trygger, TeknD

Forskare (Researchers)

Stefan Feltenmark, TeknD
Andreas Nõu, TeknD

Gästforskare (Visiting professors)

Per-Olof Gutman, professor
Vladimir Yakubovich, professor

Handläggare (Executive administrator)

Leena Druck

Doktorander (Graduate students)

Claudio Altafini
Anders Dahlén, FK, TeknL
Magnus Egerstedt, civing
Per Enqvist, civing
Torvald Ersson, civing
Camilla Landén, civing
Ryozo Nagamune
Mattias Nordin, civing, TeknL
Mikael Prytz, civing
Jonas Rappe, civing
Henrik Rehbinder, civing
Göran Sporre, civing
Mathias Stolpe, civing
Petter Ögren, civing

1.2 Biographies

[0,l,[width=30mm]received a degree ("laurea") in Electrical Engineering in 1996, from the University of Padova, Italy. In 1995 he worked for ABB Industrial Systems in Västerås, Sweden. In 1996 he held a position as process control engineer at Cerestar Italia SpA. He is currently a PhD student at the division, affiliated with the Center for Autonomous Systems. His current research interests are geometric control theory with applications to robotics.,] **Claudio Altafini**

[0,l,[width=30mm]was born in 1961. He received a civilingenjör degree in Aeronautical Engineering from KTH in 1986 and an MS degree in Engineering-Economic Systems from Stanford University in 1988 and his doctorate degree from KTH in 1993. His main research interests are nondifferentiable optimization, semidefinite programming and structural optimization.,] **Ulf Brännlund**

[0,l,[width=30mm]was born in Karlskrona, Sweden, in 1969. He did his undergraduate work in Mathematics of Science at the University of Växjö. He is presently a PhD student at the Division of Optimization and Systems Theory, and received in May 1998 the Teknisk Licenciat degree. His main professional interest is Mathematical Systems Theory, and especially Stochastic Realization theory and Identification.,] **Anders Dahlén**

[0,l,[width=30mm]has been at the Division of Optimization and Systems Theory since 1992. Since 1999 she is the executive administrator at the Department of Mathematics.,] **Leena Druck**

Magnus Egerstedt was born in 1971 in Täby, Stockholm, Sweden. He received his Master of Science-degree in Engineering Physics at the Royal Institute of Technology in 1996. Besides the MSc-degree, he also has a BA-degree from Stockholm's University, majoring in Theoretical Philosophy. He is currently a PhD-student at the division, affiliated with the Centre for Autonomous Systems, and he works on the problem of how to structure a robotic navigation system. This problem involves motion planning and control as well as coordination of different actions, using for instance a hybrid systems approach. His main interests lies in the control theoretical aspects of this area, such as robustness and stability.

[0,l,[width=30mm]was born in Upplands Väsby, Sweden, in 1971. He received a civilingenjörs degree in Engineering Physics from KTH in 1994. He is presently a PhD student at the Division of Optimization and Systems Theory.,] **Per Enqvist**

[0,l,[width=30mm]was born in Västmanland, Sweden, in 1973. He received a Master of Science degree from the School of Engineering Physics, KTH, in 1998. Presently he is a graduate student at the division and cooperates with the Centre for Autonomous Systems (CAS). His main research interests are robotics and autonomous systems.,] **Torvald Ersson**

[0,l,[width=30mm]was born in Boden in 1968. He received a civilingenjör degree in Engineering Physics from KTH in 1991, and a TeknD (PhD) degree from the Division of Optimization and Systems Theory, KTH, in 1997. Research interests include power systems optimization, stochastic programming, dual methods, decomposition methods, and large-scale optimization.,] **Stefan Feltenmark**

Anders Forsgren was born in Danderyd, Sweden, in 1961. He received a civilingenjör degree in Engineering Physics from KTH in 1985, an MS degree in Operations Research from Stanford University in 1987 and a TeknD degree in Optimization and Systems Theory from KTH in 1990. Between 1991 and 1995 he held a position as research associate at the Division of Optimization and Systems Theory, where in 1995 he was appointed Docent. Since 1995 he is an associate professor at this division. Forsgren was a Visiting Fulbright Scholar at the University of California, San Diego, during three months in 1996. His main research interest is nonlinear programming, numerical optimization in particular.

Per-Olof Gutman was born in Höganäs, Sweden on May 21, 1949. He received the Civ.-Ing. degree in engineering physics in 1973, the Ph.D. degree in automatic control, and the title of docent in automatic control in 1988, all from the Lund Institute of Technology, Lund, Sweden. As a Fulbright grant recipient, he received the M.S.E. degree in 1977 from the University of California, Los Angeles.

He taught mathematics in Tanzania 1973-1975. 1983-1984 he held a post-doctoral position with the Faculty of Electrical Engineering, Technion - Israel Institute of Technology, Haifa, Israel. 1984-1990 he was a scientist with the Control Systems Section, El-Op Electro-Optics Industries, Rehovot, Israel, where he designed high precision electro-optical and electro-mechanical control systems. In 1990 he joined the Faculty of Agricultural Engineering, Technion — Israel Institute of Technology, Haifa, where he is currently an Associate Professor.

He has spent several periods as a guest researcher at the Division of Optimization an Systems Theory, Royal Institute of Technology, Stockholm, Sweden. He was a Visiting Professor at the Laboratoire d'Automatique de Grenoble, France, 1995-96.

Xiaoming Hu was born in Chengdu, China, in 1961. He received the B.S. degree from University of Science and Technology of China in 1983. He received the M.S. and Ph.D degrees from Arizona State University in 1986 and 1989 respectively. He served as a research assistant at the Institute of Automation, Academia Sinica, from 1983 to 1984. He was Gustafsson Postdoctoral Fellow at the Royal Institute of Technology, Stockholm, from 1989 to 1990. His main research interests are nonlinear control theory, the analysis and design of nonlinear feedback systems and the applications of nonlinear dynamics in control and state estimation.

[0,l,[width=30mm]was born in Upplands Väsby, Sweden, in 1970. She received a civilingenjör degree in Engineering Physics from KTH in 1994. She is presently a PhD student at the Division of Optimization and Systems Theory.,] **Camilla Landén**

Anders Lindquist received his PhD degree from the Royal Institute of Technology, Stockholm, Sweden, where in 1972 he was appointed a Docent of Optimization and Systems Theory. From 1972 to 1974 he held visiting positions at the University of Florida, Brown University, and State University of New York at Albany. In 1974 he became an Associate Professor, and in 1980 a (full) Professor of Mathematics at the University of Kentucky, where he remained until 1983. He is now a Professor at the Royal Institute of Technology, where in 1982 he was appointed to the Chair of Optimization and Systems Theory. Since then he has also held visiting positions at the University of Padova, Italy, University of Arizona, USSR Academy of Sciences, Moscow, East China Normal University, Shanghai, and Technion, Haifa, Israel.

Presently, Anders Lindquist is the Chairman of the Mathematics Department at

the Royal Institute of Technology. He is a Member of the Royal Swedish Academy Sciences, a Fellow of the Institute of Electrical and Electronics Engineers (IEEE), and an Honorary Member the Hungarian Operations Research Society. He is an Affiliate Professor at Washington University, St Louis (since 1989) and an Advisory Board Member of the Institute for Mathematics of the Life Sciences, Texas Tech University.

Lindquist has served on many editorial boards of journals, among them the *Journal of Mathematical Systems, Estimation, and Control* (Communicating Editor), *Systems and Control Letters*, *Adaptive Control and Signal Processing*, and book series, namely *Systems and Control: Foundations and Applications*, *Applied and Computational Control, Signals, and Circuits*, and *Progress in Systems and Control*. Since 1983 he has been a member, and between 1985 and 1987 the chairman, of the steering committee for the biannual international symposia on the Mathematical Theory of Networks and Systems (MTNS).

[0,l,[width=30mm]was born in Yamaguchi, Japan, in 1972. He received Master's degree in Engineering from Osaka University in 1997. He is presently a PhD student at the Division of Optimization and Systems Theory. His research interests are applications of Nevanlinna-Pick theory with degree constraint to H^∞ control theory.,]
Ryozo Nagamune

Mattias Nordin received his civilingenjör degree in Engineering Physics from KTH in 1992, where his Masters Thesis:*Robust Control of Rolling Mills* was awarded with the VOLVO Royal Institute Technologist of 1992 as one of two that year. Subsequently he started as a Graduate Student at the Division of Optimization and Systems Theory in the project Robust Control of Electrical Drives, where his main research interest is systems with backlash or gear play. He also works in the area of robust control, especially Quantitative Feedback Theory (QFT). In 1995 he received his Licentiate Thesis:*Uncertain Systems with Backlash, Modelling, Estimation and Synthesis*. He has also published several designs for Benchmark Problems, and is generally interested in applying theoretical results to practical problems. His research is in cooperation with ABB Industrial Systems AB, Västerås, where he currently spends most of the week.

[0,l,[width=30mm]received his civilingenjör degree in Engineering Physics from KTH in 1991 and his doctorate degree in Optimization and Systems Theory from KTH in 1997. His main research interests are methods for large-scale combinatorial optimization problems, arising e.g. in various transportation science applications.,]
Andreas Nõu

Mikael Prytz was born in 1969 in Stockholm, Sweden. He has a Master of Science-degree in Engineering Physics from the Royal Institute of Technology (1993) and a Masters-degree in Engineering-Economic Systems and Operations Research from Stanford University (1998). From 1993 to 1996 he worked at Ericsson Telecom where he developed models and methods for telecommunications network design problems and participated in network design projects. In 1997 he began as an industry Ph.D. student at the department in a project that is jointly funded by Ericsson Telecom and the Swedish Research Council for Engineering Sciences. He spent the academic year 1997-98 in the MS-program at the Department of Engineering-Econonic Systems and Operations Research, Stanford University, USA. His research interests are in optimization methods for telecommunications network design problems.

[0,l,[width=30mm]was born in 1970. He received a civilingenjör degree in Vehicle Engineering from KTH in 1997. In 1998 he worked for Sigma Design & Development in Solna, Sweden. He is currently a PhD student at the Division of Optimization and Systems Theory. His main research interests are hydro power systems optimization and stochastic programming.,] **Jonas Rappe**

[0,l,[width=30mm]was born in 1972 in Värmdö, Stockholm, Sweden. He received his Master of Science degree in Engineering Physics from KTH in 1996. He is currently a PhD-student at the division, affiliated with the WARP at the Centre for Autonomous Systems. His research interests are in sensor fusion for state estimation focused on attitude estimation for walking machines and he is also interested in real-time aspects of automatic control.,] **Henrik Rehbinder**

[0,l,[width=30mm]was born in Järfälla, Sweden, in 1972. He received a civilingenjör degree in Engineering Physics from KTH in 1996. In 1997 he was employed at Telia Engineering, working with issues related to network planning for telecommunication. Since the beginning of 1998 he is a PhD student at the Division of Optimization and Systems Theory.,] **Göran Sporre**

[0,l,[width=30mm] was born in Skerike, Sweden, in 1972. He received a Master of Science degree in Vehicle Engineering from KTH in 1997. He is presently a PhD student at the Division of Optimization and Systems Theory. His main area of research is structural optimization.,] **Mathias Stolpe**

Krister Svanberg was born in Stockholm in 1950. He received his civilingenjör degree in Engineering Physics in 1975, and his TeknD degree in Optimization Theory in 1982, both from KTH. In 1993 he was appointed Docent. Between 1976 and 1985 he worked for the Contract Research Group of Applied Mathematics, and since 1985 he is a Senior Lecturer (Universitetslektor) of Optimization and Systems Theory. His main area of research is structural optimization, dealing with theory and methods for optimal design of load-carrying structures.

Claes Trygger was born in Stockholm, Sweden, in 1945. He received his civilingenjör degree in Engineering Physics in 1969 and his TeknL and TeknD degrees in Optimization and Systems Theory in 1974 and 1980, respectively; all from KTH. Since 1966 he has been employed in various positions at the Department of Mathematics at KTH, mainly in the Division of Optimization. At present he is a Senior

Lecturer of Optimization and Systems Theory. Apart from teaching, his main professional interests are control theory and mathematical biology.

Vladimir Yakubovich was born in Novosibirsk, Russia, in 1926. He was a student of Mechanics and Mathematics at Moscow University from 1946 to 1949. In 1949 he received the first prize for student scientific work and was recommended by two chairs (those of I. M. Gelfand and V. V. Nemyzki) for postgraduate education but was refused at the request of Comsomol and the Communist Party (after he had protested against discrimination of Jewish students in admittance to postgraduate studies). In 1953, after having worked for some time in industry as an engineer, he received the Candidate of Science degree (PhD), and then he served as an Assistant and an Associate Professor at Leningrad Mining Institute. From 1956 to present time he has been associated with St. Petersburg University (formerly Leningrad University), where in 1959 he received the Doctor of Science Degree. He became a (full) Professor of Mathematics in 1963 and head of the Theoretical Cybernetics Chair in 1971.

He is the author of more than 250 papers and coauthor of seven books in different areas of mathematics, especially applied mathematics and control theory. He has worked in parametric resonance theory (extending and improving some Lyapunov results), in the theory of stability of nonlinear systems, and in optimization theory. He introduced a method of "recursive aim inequalities" in the theory of adaptive systems, and an abstract theory of optimal control, extending the Pontrjagin maximum principle to many new cases. The "Kalman-Yakubovich-Popov Lemma" connects two areas of control theory, frequency methods and Lyaponov methods, and it is also of importance in stochastic realization theory. His main results in recent years concern new aspects of linear-quadratic optimization problems.

Yakubovich has served on the editorial boards of Siberian Mathematical Journal (1973-1980), Systems and Control Letters (1981-1988) and Dynamics and Control (since 1990). He has served on many scientific committees and is a member of several scientific societies in Russia. In 1991 he was awarded the Norbert Wiener Prize by the Russian Academy of Natural Sciences. Since 1991 he is a corresponding member of the Russian Academy of Sciences and since 1992 a member of the Russian Academy of Natural Science.

[0,l,[width=30mm]was born in 1974 in Stockholm, Sweden. He received his Master of Science degree in Engineering Physics at the Royal Institute of Technology in 1998. He is presently a Ph.D. student at the Division of Optimization and Systems Theory at the Royal Institute of Technology. He is affiliated with the Center for Autonomous Systems. His research interests are the control theory of robotics and hybrid systems.,] **Petter Ögren**

1.3 Visiting and interacting scientists

- Professor Jürgen Ackermann, Institute for Robotics and System Dynamics, DLR, German Aerospace Research Establishment, Wessling, Germany
- Professor Tomas Björk, Department of Finance, Stockholm School of Economics
- Professor Christopher I. Byrnes, Department of Systems Science and Mathematics, Washington University, St. Louis, Missouri, USA
- Professor W. P. Dayawansa, Department of Mathematics, Texas Tech University, Lubbock, Texas, USA
- Professor Leonid Faybusovich, Department of Mathematics, University of Notre Dame, Notre Dame, Indiana, USA
- Professor A. L. Fradkov, Department of Mathematics and Mechanics, St. Petersburg State Technical University, Russia
- Professor Ruggero Frezza, Dipartimento di Elettronica, Universita di Padova, Padova, Italy
- Professor Tryphon T. Georgiou, Department of Electrical and Computer Engineering, University of Minnesota, Minneapolis, Minnesota, USA
- Dr. Karl H. Johansson, Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, USA
- Professor Philip E. Gill, Department of Mathematics, University of California, San Diego, La Jolla, California, USA
- Dr. S. V. Gusev, Department of Mathematics, St. Petersburg University, St. Petersburg, Russia
- Professor Jan Holst, Department of Mathematical Statistics, Lund University, Lund, Sweden
- Dr. Ilya Ioslovich, Faculty of Agricultural Engineering, Technion, Haifa, Israel
- Professor Krzysztof C. Kiwiel, Systems Research Institute, Warsaw, Poland
- Professor Claude Lemaréchal, INRIA Rhône-Alps, Grenoble, France
- Professor P. O. Lindberg, Division of Optimization, Department of Mathematics, Linköping University
- Dr. John Lygeros, Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, USA
- Dr. Jorge Marí, Adtranz, Västerås, Sweden
- Professor Clyde F. Martin, Department of Mathematics, Texas Tech University, Lubbock, Texas, USA
- Professor György Michaletzky, Department of Probability Theory and Statistics, Eötvös Lorand University, Budapest, Hungary
- Professor Walter Murray, Department of Engineering Economic Systems and Operations Research, Stanford University, Stanford, California, USA
- Professor Jan-Eric Nilsson, The Swedish National Road and Transport Research Institute, Borlänge, Sweden
- Professor Giorgio Picci, Department of Electronics and Informatics, University of Padova, Padova, Italy
- Professor Alfredo Piria, Department of Mathematics, Facultad Ingeneria, Montevideo, Uruguay
- Professor Shankar Sastry, Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, USA

1.4 Networks

- European Research Consortium for Informatics and Mathematics (ERCIM): Working Group on Control and System Theory
- European Research Network for Systems Identification (ERNSI)
- INTAS Network on Robust Control
- NorFa Network on Structural Optimization.
- Strategic Research Consortium of Autonomous Systems, KTH

2 Research

2.1 List of projects

- Advanced optimization methods for crew and vehicle scheduling
- Autonomous systems
- Control theoretic smoothing splines
- Financial economics
- Geometric theory of linear stochastic systems
- Hybrid control of autonomous systems
- KTH optimization laboratory
- Large-scale nonlinear programming
- Models and methods for structural optimization
- Optimal damping of forced oscillations in discrete-time systems
- Optimization in telecommunications network design
- Optimization of power systems under uncertainty
- Process modeling, operator training simulation and optimization applied to paper board manufacturing
- Railway timetabling on track networks
- Rational Nevanlinna-Pick interpolation with degree constraints
- Regularization of Zeno hybrid automata
- Robust control of electrical drives
- Robust quality control for paper manufacturing
- Semidefinite programming and structural optimization
- Some problems in navigation and motion control of nonlinear systems
- Stochastic realization theory and identification
- The rational covariance extension problem

2.2 Description of projects

Advanced optimization methods for crew and vehicle scheduling

Researchers: Andreas Nõu, in cooperation with K. C. Kiwiel, Systems Research Institute, Warsaw, Poland and P. O. Lindberg, Linköping University.

Sponsor: The Swedish Transport Research Board (TFB).

In this project we use advanced dual methods to solve large-scale 0-1 problems. The problems we have in mind are very large, sparse, set covering problems that arise e.g. in airline crew scheduling. The dual multipliers are used heuristically to generate near optimal 0-1 solutions.

We apply a recent extension of the Bregman proximal method for convex programming to LP relaxations of 0–1 problems. Approximate relaxed solutions are used to construct primal feasible solutions via a randomized heuristic. Encouraging experience is reported, [A12].

Autonomous systems

Researchers: Anders Lindquist, Xiaoming Hu, P.-O. Gutman, Magnus Egerstedt, Henr ik Rehbinder, Claudio Altafini, Torvald Ersson and Petter Ögren within the framework of th e Center for Autonomous Systems.

Sponsor: The Strategic Research Foundation (Stiftelsen för strategisk forskning).

This is a broad and long-term project in collaboration with the Division of Computer Vision and Active Perception, (Numerical Analysis and Computing Science), Department of Mechatronics and Machine Elements, and Department of Signals, Sensors and Systems, which together with the Division of Optimization and Systems Theory form a research consortium supported by a grant from the Strategic Research Foundation. By autonomous systems is meant technical systems (such as mobile robots) that are capable of performing advanced tasks in unpredictable environments. Specific subprojects are reported separately.

Control theoretic smoothing splines

Researchers: Magnus Egerstedt, in cooperation with Clyde F. Martin (Texas Tech University), and Shan Sun (Texas Tech University).

Sponsors: The Swedish Foundation for Strategic Researches (SSF), NSF, and NASA.

When planning trajectories for linear control systems, a demand that arises naturally in, for instance, air traffic control, noise contaminated data interpolation, and planning for switched control systems, is that the curve interpolate through given points or intervals at given times. We address this problem by showing how linear optimal control techniques, together with mathematical programming, can be used to solve the problem in a numerically feasible way. We thus provide a theoretical framework for producing a rich set of curves called generalized smoothing splines.

Financial economics

Researchers: Camilla Landén, in cooperation with Tomas Björk (Stockholm School of Economics).

The goal of this project is to study the mathematical theory of financial derivatives.

During the year we have considered the problem of inverting the yield curve for short rate models. We have taken the point of view that a difference between the theoretical and the empirical term structure indicates that you have misspecified the martingale measure. Consequently, we try to find a Girsanov transformation such that the two term structures will agree under the new martingale measure. Since the general problem turns out to be rather difficult we simplify the problem by requiring the forward rate volatilities to be the same under the original and the new martingale measure. This allows us to use the forward rate model to do the fitting.

Our main result is that inverting the yield curve using forward rate volatilities works if and only if the original short rate model is affine. As a corollary we obtain that the only generic short rate models are the affine models.

Geometric theory of linear stochastic systems

Researchers: Anders Lindquist, in cooperation with Giorgio Picci (University of Padova) and Gy. Michaletzky (Eötvös Lorand University, Budapest).

Sponsors: The Swedish Research Council for Engineering Sciences (TFR) and the Göran Gustafsson Foundation.

The objective of this project is to develop a comprehensive geometric theory for state-space modeling of stochastic processes within the coordinate-free framework of Markovian splitting subspaces and with emphasis on systems theoretical concepts, and to apply these results to problems in identification and model reduction. A theory for linear stochastic systems has been developed which describes structural systems-theoretic properties in the geometric language of Hilbert space theory. A monograph, jointly authored by Lindquist and Picci, is under preparation. Recent results include:

- We have developed a synthesis of stochastic realization theory and geometr ic control theory in the style of Wonham and Basile and Marro.
- We have generalized the well-known characterization of the solutions of the algebraic Riccati equation in terms of Lagrangian subspaces invariant under the corresponding Hamiltonian to the larger solution set of the algebraic Riccati inequality. The discrete-time Riccati equation has been studied in detail.
- Connections have been established between stochastic realization theory and identification algorithms based on canonical correlation analysis. Some geometric alternatives to subspace identification methods are con sidered.
- A causal realization theory for stochastic models of random phenomena that are spatially distributed have been developed (J. Sand).
- A procedure for reconstructing the lost state when a "black out" of state information has occurred during a finite interval of time but noisy output observation still are.

Hybrid control of autonomous systems

Researchers: Anders Lindquist, Xiaoming Hu, P.-O. Gutman, Magnus Egerstedt, Henrik Rehbinder, Claudio Altafini, Torvald Ersson and Petter Ögren.

Sponsor: The Swedish Foundation for Strategic Researches (SSF).

This project is part of the research effort of the Center for Autonomous Systems. In this project we use a hybrid system approach to study some issues concerning the integration of control and sensor systems for a mobile manipulator. In particular, the following issues are studied.

1. Modeling of basic behaviors as dynamic systems. In order to take advantage of HDS methods, one should model individual behaviors of a robot (action responses to sensory inputs) as dynamical systems, or as a set of differential or/and difference equations. Then one can study problems such as path planning and obstacle avoidance for systems with possibly nonholonomic constraints.
2. Modeling of tasks as hybrid dynamic systems. In a Behavior Based robot architecture, many behaviors are affecting the system simultaneously. Therefore questions concerning safety, task-achievement and liveliness (non-blocking behaviors) are hard to answer due to the complexity of the system. However, if these behaviors could be modeled as nodes in a hybrid automata, features about the system could be proved.
3. Sensor fusion. The multiple sensor problem, known as sensor fusion, has been studied extensively, but a fully satisfying solution has not yet been provided and many research issues are still open. We study the basic problems of designing and tailor-making filter algorithms for our applications as well as more general filtering problems for sensors in distributed control systems.

KTH optimization laboratory

Researchers: Ulf Brännlund, Stefan Feltenmark, Anders Forsgren, Andreas Nõu, Mikael Prytz, Jonas Rappe, Göran Sporre, Mathias Stolpe, Krister Svanberg.

This project aims at creating a productive research environment for development of optimization methods and at spreading modern optimization practice in Swedish industry. This is done by collecting state-of-the-art portable optimization routines as well as optimization problems and keeping them available in a network of work stations. This obviously will facilitate research, but through our projects and through making the routines available for testing, we also fulfill the other goal.

A partial list of routines include:

MINOS, SNOPT, QPOPT, LSSOL, NPOPT	(Gill et al, Stanford and UCSD)
CPLEX	(Cplex Corporation)
MMA	(Svanberg, KTH)
GRG2	(Lasdon, U Texas)
RELAX	(Bertsekas, MIT)
NETFLO, NETSIDE	(Kennington, S Methodist U)
NLPQL	(Schittkowski, U Bayreuth)
NOA3	(Kiwiel, Polish Academy of Sciences)
RSDNET, RSDTA	(Hearn, U Florida)
GAMS	(GAMS)
ELSUNC, ENLSIP	(Umeå University)

The routines reside in a Unix workstation environment, in which we have written an interfaces to Matlab for several routines, thereby making them easy to use. These interfaced routines have been used extensively, both in our own research and for educational purposes.

Large-scale nonlinear programming

Researchers: Anders Forsgren and Göran Sporre, in cooperation with Philip E. Gill (UCSD).

Sponsor: The Swedish Natural Science Research Council (NFR).

The goal of this project is the development of computationally efficient methods for solving large sparse nonlinear optimization problems. We focus on methods that utilize second-derivatives, since we expect such methods to prove more robust and efficient than methods that only use first-derivative information.

Recent algorithmic work has been directed towards penalty-barrier methods for general nonlinear programming methods. A method, solving a primal-dual system of equations at each iteration, utilizing an augmented penalty-barrier merit function, has been developed [A7]. The current focus of Sporre's research is on primal-dual interior methods, convergence properties in particular.

Models and methods for structural optimization

Researchers: Krister Svanberg, Ulf Brännlund, and Mathias Stolpe.

Sponsor: The Swedish Research Council for Engineering Sciences (TFR).

Structural optimization deals with optimal design of load-carrying structures. The purpose of this project is to develop mathematical models and efficient numerical methods for different types of structural optimization problems.

During the year, we have developed methods for topology optimization of certain linearly elastic structures. The variables are densities of the elements in the structure, and in the end these variables are required to be zero or one ("mass or no mass"). The objective function is structural weight and the constraint functions are stresses and compliances under multiple load conditions. We have also developed a new globally convergent version of our "method of moving asymptotes" (MMA) and implemented it in Fortran and Matlab. The codes are available for academic usage, and they have already been distributed to several research groups who explicitly asked for it.

Optimal damping of forced oscillations in discrete-time systems

Researchers: Anders Lindquist and Vladimir A. Yakubovich.

Sponsors: The Swedish Research Council for Engineering Sciences (TFR), the Royal Swedish Academy of Sciences, NUTEK and INTAS.

In this project we consider a linear discrete-time control system affected by additive harmonic disturbances with known frequencies but unknown amplitudes and phases. The problem is to damp this forced oscillation in an optimal fashion by output feedback and to track a given signal. To this end we design a robust optimal regulator which is universal in the sense that it does not depend on the unknown amplitudes and phases and is optimal for all choices of these values. In [A13] we show that, under certain natural technical conditions, an optimal universal

regulator (OUR) exists in some suitable class of linear or nonlinear stabilizing and realizable regulators, provided the dimension of the output is no smaller than the dimension of the quasi-harmonic disturbance. When this dimensionality condition is not satisfied, the existence of an OUR is not a generic property. We have also shown that any OUR for this (deterministic) problem is an optimal regulator for a class of stochastic control problems of similar structure. Nonrationals solutions are also being studied.

We stress that our solutions are optimal in the sense stated above only, arbitrary universal optimal regulator. Therefore it is an important for an property of our procedure that it allows for a considerable degree of design freedom, and optimality should be regarded as one of several design specifications.

Optimization in telecommunications network design

Researchers: Mikael Prytz and Anders Forsgren (advisor).

Sponsor: Swedish Research Council for Engineering Sciences, Ericsson Telecom.

This project considers models and optimization methods for telecommunications network design problems. The focus is on practical solution methods for real problems that are relevant for network designers in the tele- and datacommunications industry.

Currently a capacity dimensioning problem in multicast-enabled datacom networks is studied. The problem arises when designing a new network or when expanding an existing network. Our model for the problem may also be used to reserve resources in an existing network. Some examples of multicast traffic are real-time distribution of video/audio/data to subscribers (who "tune-in" to TV-channels, stock-tickers, etc.), video/voice-conferencing with virtual whiteboards, time-critical replication of distributed databases (e.g. Yahoo-type services and Storage Area Networks), and distributed communication. The crucial feature is that identical copies of the same information is sent to several receivers at the same time. A multicast-enabled datacom network saves network resources by delaying information duplication as far out in the network as possible.

Our model is a mixed integer program (MIP) with a discrete set of capacities (having different costs) available for the possible connections between the routers in the network. A set of multicast traffic requirements, each with participating nodes and required resources, is given. The model selects connection capacities and traffic routing while striving to minimize cost. Real problems easily result in programs with thousands of binary variables and tens of thousands of continuous variables. We consider different methods to solve relaxations of the program.

Optimization of power systems under uncertainty

Researchers: Stefan Feltenmark, in cooperation with Jan Holst (Lund University).

Sponsor: ITM, Vattenfall, Sydkraft, Elforsk.

Within this project, we study optimization of hydro-thermal power systems in situations with imperfect information about problem data. Such data is future dam inflows, power prices, and power demand. We address these problems by *stochastic programming*, combined with advanced sampling techniques. The project runs from January 1998.

Process modeling, operator training simulation and optimization applied to paper board manufacturing

Researchers: Per-Olof Gutman, Anders Lindquist, Xiaoming Hu, in cooperation with with Bengt Nilsson (AssiDomän Carton Board AB, Frövi), Lars Ödberg (AssiDomän Corporate R&D, Skärblacka), Hilding Elmqvist (Dynasim AB, Lund), and Pontus Ryd (Solvina AB, Göteborg).

Sponsors: The Swedish National Board for Industrial and Technical Development (NUTEK) through its KTS (Complex Technical Systems) program, and AssiDomän Carton Board AB, AssiDomän Corporate R&D, Dynasim AB, and Solvina AB.

The project started in April 1999. The aim of the project is to integrate existing models of the paper board manufacturing process at AssiDomän Carton Board AB, together with on-line identification routines, into a comprehensive Modelica model with the purpose of interactive operator simulation and operator assisted optimization of important quality variables.

Dynamic models will be developed for those subprocesses for which suitable models do not exist. A library of reusable model components will be developed in the new modeling language Modelica.

The project can be seen as a continuation of the project "Robust quality control for paper manufacturing" mentioned below.

Railway timetabling on track networks

Researchers: Andreas Nõu, in cooperation with Jan-Eric Nilsson, The Swedish National Road and Transport Research Institute.

Industrial contacts: The Swedish National Rail Administration.

This is a project concerning the optimal allocation of scarce track capacity between a number of different railway companies offering various services on a railway track network.

In a previous project we considered a stretch of single track, please refer to [A3] for details. The current project aims to extend the optimization algorithms to cope with *networks* of track and to increase the model accuracy when compared to current operating practice in Sweden. A computational evaluation will be carried out in cooperation with The Swedish National Rail Administration. Preliminary computational experience is encouraging.

Rational Nevanlinna-Pick interpolation with degree constraints

Researchers: Anders Lindquist and Ryozo Nagamune in cooperation with C. I. Byrnes (Washington University, St Louis) and T. T. Georgiou (University of Minesota).

Sponsors: The Swedish Research Council for Engineering Sciences (TFR) and the Göran Gustafsson Foundtion.

Several important problems in circuit theory, robust stabilization and control, signal processing, and stochastic systems theory lead to a Nevanlinna-Pick interpolation problem, in which the interpolant must be a rational function of at most a prescribed degree. We have obtained a complete parameterization of all such solutions in terms of the zero structure of a certain function appearing naturally in several applications, and this parameterization can be used as a design instrument.

We have developed an algorithm to determine any such solution by solving a convex optimization problem, which is the dual of the problem to maximize a certain generalized entropy critierion [R4]. Software based on state space concepts is being developed, and the computational methods are applied to several problems in systems and control.

Solutions of bounded complexity for generalized interpolation in H^∞ are also being studied together with the connections to the commutant lifting theorem of Sarason.

In [R2] and [R3] we present a new approach to spectral estimation, which is based on the use of filter banks as a means of obtaining spectral interpolation data. Such data replaces standard covariance estimates. A computational procedure for obtaining suitable pole-zero (ARMA) models from such data is presented. The choice of the zeros (MA-part) of the model is completely arbitrary. By suitably choices of filter-bank poles and spectral zeros the estimator can be tuned to exhibit high resolution in targeted regions of the spectrum.

In [R5] we study certain manifolds and submanifolds of positive real transfer functions, describing a fundamental geometric duality between filtering and Nevanlinna-Pick interpolation. More precisely, we prove a duality theorem, which we motivate in terms of both the interpolation problem, and a fast algorithm for Kalman filtering, viewed as a nonlinear dynamical system on the space of positive real transfer functions.

Regularization of Zeno hybrid automata

Researchers: Magnus Egerstedt, in cooperation with Karl H. Johansson (UC Berkeley), John Lygeros (UC Berkeley), and Shankar Sastry (UC Berekeley).

Sponsors: The Swedish Foundation for Strategic Researches (SSF), the Swedish Foundation for International Cooperation in Research, and DARPA.

A Zeno hybrid system is a dynamic system, with both continuous and discrete dynamics, that admits executions where an infinite number of discrete transitions occur in a finite amount of time, thus (formally) preventing time from diverging. Zeno executions typically arise due to modeling over-abstraction, and can cause problems when simulating hybrid systems or synthesizing controllers for them.

Conventional, sliding mode control can be thought of as a special case of the Zeno phenomenon. Motivated by this observation, we are investigating similar techniques, based on regularizations, for resolving the Zeno problem by extending the Zeno automaton beyond the Zeno time. This is done by investigating the behavior of a parameterized family of non-Zeno hybrid automata, converging to the original Zeno automaton.

Robust control of electrical drives

Researchers: P. O. Gutman, Mattias Nordin, Xiaoming Hu and Anders Lindquist.

Industrial contact: ABB Industrial Systems AB.

The aim of this project is to combine robust linear control with nonlinear control elements, implemented in a microprocessor, that alleviate the effects of the process nonlinearities. In particular electrical drives with friction, backlash and uncertain loads and disturbances are being studied. The emphasis is on applicable solutions, i.e. that the algorithms an methods should work in real life. Some of the hitherto achieved results are:

- New models for backlash and gear play has been developed, verified by measurements and simulation in an industrial environment.
- Systematic design methods, based partly on the Horowitz robust design methodology and the describing function method, has been and are being developed for uncertain systems including hard nonlinearities, such as friction and backlash.
- Methods to identify the backlash gap has been developed.
- Methods were developed to compute value sets for uncertain transfer functions.
- Tuning rules for PI and PID controllers, have been developed for resonant systems.

Robust quality control for paper manufacturing

Researchers: P.-O. Gutman, in cooperation with Bo Wahlberg, Torsten Bohlin, Alf Isaksson, and Jens Pettersson (Division of Automatic Control, KTH), and with Bengt Nilsson (Assi-Domän Carton Board AB, Frövi).

Sponsors: The Swedish National Board for Industrial and Technical Development (NUTEK) through its REGINA program, and AssiDomän Carton Board AB.

The aim of the project is to find dynamic models of a paper board machine, connecting variables that are manipulated by the operators with central laboratory measured quality variables, such as bending stiffness and surface coarseness, in order to to predict the quality variables on-line. The predictors will be used as an operator aid, as an optimization tool, and possibly in automatic quality control. To reach the aim, several difficult theoretical and methodological problems are addressed, such as handling missing data and outliers, the time variability of the process and other process changes, the influence of the unmeasurable variability of the raw material, etc. The industrial process on which this program is conducted is the paper board manufacturing machine at AssiDomän Carton Board AB, Frövi.

The project was concluded this academic year with the licentiate thesis, Jens Pettersson (1998): "On model based estimation of quality variables for paper manufacturing", TRITA-S3-REG-9804, Automatic Control, Department of Signals, Sensors, and Systems, KTH, Stockholm. The bending stiffness predictor described in the thesis is in operative use at the AssiDomän Carton Board AB, Frövi. Contributions emanating from the project include [A8].

Semidefinite programming and structural optimization

Researchers: Ulf Brännlund, Mathias Stolpe and Krister Svanberg.

Sponsor: The Swedish Research Council for Engineering Sciences (TFR).

Semidefinite programming is a matrix generalization of linear programming which recently has been proven to be valuable in solving many applications of convex optimization.

Structural optimization deals with computer-aided optimal design of load carrying structures. A typical objective is to minimize the structural weight subject to various constraints on structural stiffness and strength.

The subject of this project is to develop mathematical models and numerical methods for optimizing the topology of different types of load-carrying structures. Such problems are in general much harder than for example problems dealing only with element sizes. The emphasis in this project is development of methods for

semidefinite programming with the special structure found in truss topology design problems.

Some problems in navigation and motion control of nonlinear systems

Researchers: Xiaoming Hu, in cooperation with R. Frezza (Univ. of Padova) and C.F. Martin (Texas Tech. Univ.).

Sponsor: The Swedish Research Council for Engineering Sciences (TFR).

This project is devoted to several key issues arising from navigation and motion control of an autonomous vehicle, which are also important in their own right, to nonlinear control, robust control and nonlinear programming. 1.The problem of pathing planning is studied. The problem of finding a feasible trajectory and generating the corresponding control action for nonlinear dynamical control systems, even without a drift vector field, is in general difficult. In some application fields, such as mobile robotics, fast and efficient algorithms are required and one has to sometimes sacrifice optimality in order to follow a reasonable path in an efficient way. In this methodology, spline functions are very useful in generating a path. 2. Navigation and motion control algorithms are studied. The key issue here is robustness. It is a robustness problem because of large variations in the vehicle mass and velocity and the force generation mechanism, and because of disturbances and noises in the output measurements. The related problem of global stabilization of nonlinear systems is also studied. 3. Planing an optimal path for systems with kinematic constraints such as a car-like robot requires dealing with nonconvex programming. We will study the related issues so that a feasible solution is easier to compute.

Stochastic realization theory and identification

Researchers: Anders Lindquist, Anders Dahlén and Jorge Marí, in cooperation with Giorgio Picci (University of Padova).

Sponsors: The Swedish Research Council for Engineering Sciences (TFR) and the Göran Gustafsson Foundation.

In this project we analyze a class of identification algorithms based on canonical correlation analysis in the light of recent results on stochastic systems theory. In principle these so called "subspace methods" can be described as covariance estimation followed by stochastic realization. The method offers the major advantage of converting the nonlinear parameter estimation phase in traditional ARMA models identification into the solution of a Riccati equation but introduces at the same time some nontrivial mathematical problems related to positivity. The reason for this is that an essential part of the problem is equivalent to the well-known rational covariance extension problem. Therefore the usual deterministic arguments based on factorization of a Hankel matrix are not valid, something that is habitually overlooked in the literature.

We have demonstrated that there is no guarantee that several popular subspace identification procedures will not fail to produce a positive extension, unless some rather stringent assumptions are made which, in general, are not explicitly stated. These assumptions are equivalent to the condition that the positive and algebraic degrees of a certain estimated covariance sequence coincide. In [A4] we describe how to generate data with the property that this condition is not satisfied. Using this data we have shown through simulations that several subspace identification algorithms exhibit massive failure.

Therefore we have studied alternative identification strategies. In [A15] we consider a three-step procedure for identification of time series, based on covariance extension and model reduction, and we present a complete analysis of its statistical convergence properties. A partial covariance sequence is estimated from statistical data. Then a high-order maximum-entropy model is determined, which is finally approximated by a lower-order model by stochastically balanced model reduction. Such procedures have been studied before, in various combinations, but an overall convergence analysis comprising all three steps has been lacking. Supposing the data is generated from a true finite-dimensional system which is minimum phase, it is shown that the transfer function of the estimated system tends in $\mathcal{H}^\infty$ to the true transfer function as the data length tends to infinity, if the covariance extension and the model reduction is done properly. The proposed identification procedure, and some variations of it, are evaluated by simulations. In particular, these simulations show that our procedure compares favorably to the subspace methods.

The rational covariance extension problem

Researchers: Anders Lindquist and Per Enqvist, in cooperation with C. I. Byrnes (Washington University, St Louis) and S. V. Gusev (University of St. Petersburg).

Sponsors: The Swedish Research Council for Engineering Sciences (TFR) and the Gran Gustafsson Foundation.

The minimal rational covariance extension problem is a fundamental problem in systems theory, control theory, and signal processing, many aspects of which have remain unsolved for a long time. In a recent series of papers we formalized the observation that filtering and interpolation induce complementary, or "dual" decompositions of the space of positive real rational functions of degree less than or equal to n. From this basic result about the geometry of the space of positive real functions, we were able to deduce two complementary sets of conclusions about positive rational extensions of a given partial covariance sequence. On the one hand, by viewing a certain fast filtering algorithm as a nonlinear dynamical system defined on this space, we are able to develop estimates on the asymptotic behavior of the Schur parameters of positive rational extensions. On the other hand we were also able to provide a characterization of all positive rational extensions of a given partial covariance sequence. Indeed, motivated by its application to signal processing, speech processing and stochastic realization theory, this characterization is in terms of a complete parameterization using familiar objects from systems theory and proves a conjecture by Georgiou. However, our basic result also enabled us to analyze the robustness of this parameterization with respect to variations in the problem data.

In [A2] we present a convex optimization problem for solving the rational covariance extension problem. Given a partial covariance sequence and the desired zeros of the modeling filter, the poles are uniquely determined from the the minimum of the corresponding optimization problem. In this way we obtain an algorithm for the covariance extension problem, as well as a constructive proof of Georgiou's conjecture.

In [R1] we apply these principles to the design of certain ARMA filters. Because these filters can be realized in lattice-ladder form, and because one can prescribe the "notches" in the power spectrum of the ARMA model, these filters are referred to as "lattice-ladder notch" filters, or LLN filters. It is shown that LLN filters are the

most general class of modeling filters of degree at most n, which shape white noise into a process with the observed covariance data. Moreover, in terms of entropy integrals, we derive several versions of a convex optimization problem, which leads to an effective computation of the parameters in the lattice-ladder filter realization of the general ARMA model of the finite data.

Several other classes of convex optimization problems are also studied in the context of entropy maximization, leading to alternative design strategies for signal processing.

3 Education

3.1 Undergraduate courses

5B1712 Optimization for F, 4 p (*Optimeringslära för F)*

Instructor: Krister Svanberg.

Assistants: Torvald Ersson, Magnus Egerstedt and Stefan Feltenmark.

The course gives knowledge about basic concepts and theory for optimization, useful models, and numerical solution methods. Some subjects dealt with in the course are: Linear programming, network flows, nonlinear programming, convexity, Lagrangean relaxation, and duality.

5B1722 Applied Optimization for T and M, 4 p (*Tillämpad optimeringslära för T och M)*

Instructor: Claes Trygger.

Assistants: Per Enqvist, Stefan Feltenmark and Mikael Prytz.

The course gives knowledge about basic concepts and theory for optimization, useful models, and numerical solution methods. It also gives training in formulating and solving optimization problems. Some subjects dealt with in the course are: Linear programming, network flows, integer programming, deterministic dynamic programming, and nonlinear programming.

5B1742 Mathematical Systems Theory, 4 p (*Matematisk systemteori)*

Instructor: Claes Trygger.

Assistant: Henrik Rehbinder.

The course gives knowledge about basic concepts in mathematical systems theory. Some subjects dealt with in the course are: Linear control systems, realization theory, feedback, stability, linear-quadratic optimal control, and Kalman filtering.

5B1750 Optimization for E and D, 4 p (*Optimeringslära för E och D)*

Instructor: Krister Svanberg.

Assistants: Torvald Ersson, Jonas Rappe and Petter Ögren.

The course gives knowledge about basic concepts and theory for optimization, useful models, and numerical solution methods. It also gives training in formulating and solving optimization problems. Some subjects dealt with in the course are: Linear programming, network flows, integer programming, deterministic dynamic programming, and nonlinear programming.

5B1810 Mathematical Programming, 5 p
(*Matematisk programmering)*

Instructor: Stefan Feltenmark.

Assistant: Göran Sporre.

The course should deepen and broaden the theoretical and methodological knowledge in mathematical programming. Some subjects dealt with in the course are: Interior point methods for linear programming, stochastic programming, quadratic programming, SQP methods for nonlinear programming, Lagrangian relaxation for integer programming, and semidefinite programming.

5B1822 Advanced Course in Mathematical Systems Theory, 4 p
(*Matematisk systemteori, fortsättningskurs)*

Instructors: Anders Lindquist and Per Enqvist.

The course should deepen and broaden the theoretical and methodological knowledge in mathematical systems theory. Some subjects dealt with in the course are: Geometric control theory, modeling of linear stochastic systems, stochastic realization theory.

5B1832 Systems Engineering, 8 p
(*Systemteknik)*

This course is equivalent to the course 5B1842 Methods of Systems Engineering together with the course 5B1846 Applied Systems Engineering.

5B1842 Methods of Systems Engineering, 4 p
(*Systemtekniska metoder)*

Instructor: Claes Trygger.

Assistant: Mathias Stolpe.

The course gives knowledge about quantitative methods in operations research. Some subjects dealt with in the course are: Queueing theory, inventory theory, stochastic dynamic programming, and Markov decision processes.

5B1846 Applied Systems Engineering, 4 p
(*Tillämpad systemteknik)*

Instructors: Ulf Brännlund and Krister Svanberg.

Assistant: Mathias Stolpe.

The course gives deeper knowledge about some quantitative methods for analysis and design of technical systems. Some subjects dealt with in the course are: LCC analysis, multi-echelon spare parts optimization, and inventory control.

5B1852 Mathematical Economics, 4 p
(*Matematisk ekonomi)*

Instructor: Claes Trygger.

Assistant: Anders Dahlén.

The course gives basic knowledge in modern mathematical microeconomics. Some subjects dealt with in the course are: Behavior of the firm, individual preferences, consumer demand, economic efficiency, competetive equilibrium, game theory, and welfare theory.

5B1862 Stochastic calculus and the theory of capital markets, 5 p
(*Stokastisk kalkyl och kapitalmarknadsteori)*

Instructors: Tomas Björk and Camilla Landén.

The course gives knowledge in the basic theory of stochastic differential equations and Ito calculus and their applications in the theory of capital markets. The focus will mainly be on arbitrage pricing of derivative securities such as options and bonds.

5B1872 Optimal Control Theory, 4 p
(*Optimal styrteori)*

Instructor: Claes Trygger.

Assistant: Magnus Egerstedt.

The course gives knowledge in classical calculus of variations as well as in modern theory of optimal control. Some subjects dealt with in the course are: The Pontryagin maximum principle, classical theory of variations, and dynamic programming in continuous time.

5B1890 Optimization Modeling, 4 p
(*Optimeringsmodellering)*

Instructors: Ulf Brännlund and Stefan Feltenmark.

The course is based on the solution of practical optimization problems. The intent is to practically model optimization problems and to apply the methodological skills that have been acquired in preceding courses. In addition, the participants in the course become acquainted with modern optimization software. The solution of the problems is carried out on a project basis in small groups. An important aspect of the course is cooperation within the group as well as presentation in talking and writing.

3.2 Graduate courses

5B5760 Introduction to Nonlinear Control Systems, 5 p

Instructor: Xiaoming Hu.

The purpose of this course is to present the fundamentals of the theory and application of nonlinear control systems, with special emphasis on the geometric approach. In particular, this course will provide methods for analysis and synthesis of nonlinear feedback control systems.

5B5780 Hybrid Dyanmical Systems, 5 p

Organizer: Xiaoming Hu.

The course is a seminar course on hybrid dynamical systems. A hybrid system has two distinct types of components: subsystems with continuous dynamics (continuous in state space, in continuous time or discrete time) and subsystems with discrete event dynamics, that interact with each other.

5B5840 Numerical Nonlinear Programming, 5 p

Instructor: Anders Forsgren.

This course is primarily intended for graduate students in optimization and systems theory, or other graduate students with a good background in optimization. The course deals with algorithms and fundamental theory for nonlinear finite-dimensional optimization problems. Fundamental optimization concepts, such as convexity and duality are also introduced. The main focus is nonlinear programming, unconstrained and constrained. Areas considered are unconstrained minimization, linearly constrained minimization and nonlinearly constrained minization. The focus is on methods which are considered modern and efficient today.

5B5855 Applied Nonlinear Optimization, 5 p

Instructor: Anders Forsgren.

This course is primarily intended for graduate students in areas other than optimization. No specific background in optimization is required, and the course is not intended for students that have taken other optimization courses at the division. The course deals with algorithms and fundamental theory for nonlinear finite-dimensional optimization problems. Fundamental optimization concepts, such as convexity and duality are also introduced.

5B5880 Convexity and Duality in $\Re^n$, 5 p

Instructor: Ulf Brännlund.

This course is primarily intended for graduate students in optimization and systems theory, but other students are also welcome. The course deals with finite dimensional convex analysis. The emphasis of the course is on the fundamental theory but its implications for solving convex minimization problems by iterative methods are also highlighted.

3.3 Licentiate thesis

[T1] Jöran Petersson, *Algorithms for fitting two classes of exponential sums to emiprical data*, Division of Optimization and Systems Theory, Department of Mathematics, KTH, 1998. Advisor: Kenneth Holmström/Anders Lindquist.

3.4 Master theses (*Examensarbeten)*

5B1022 Master Thesis in Optimization and Systems Theory, 20 p (*Examensarbete i optimeringslära och systemteori)*

[T2] F. Armerin (F), *Cooperation in oligopolies with firms of different sizes.* Advisor: U. Brännlund and H. Lang. (E214)

[T3] K. Bodvik (F), *Integer optimization in train scheduling.* Performed at University of Florida. Advisor: P. Pardalos and R. Ahuja/K. Svanberg. (E210)

[T4] M. Blomberg (F), *Asset liabililty management.* Performed at Alfred Berg. Advisor: S. Feltenmark. (E208)

[T5] P. Erikson (F), *Congestion toll pricing of aggregated traffic networks.* Performed at University of Florida. Advisor: R. L. Francis/K. Svanberg. (E205)

[T6] M. Gillberg (F), *Interaction of speech and packet data users in a radio network.* Performed at Ericsson Radio Systems AB. Advisor: A. Forsgren. (E203)

[T7] A. Granström (F), *An outer product modified Cholesky factorization.* Performed at Stanford University. Advisor: W. Murray/A. Forsgren. (E213)

[T8] J. Grebäck (F), *A kinematic approach to motion planning of a mobile manipulator.* Performed at Centre for Autonomous Systems, KTH. Advisor: X. Hu. (E216)

[T9] I. Haglund (F), *Pricing of insurance policies.* Performed at Skandia. Advisor: U. Brännlund. (E207)

[T10] M. Hydén (F), *Multifactor models of the term structure of interest rates.* Performed at JP Bank Investment Management AB. Advisor: T. Björk. (E202)

[T11] K. Jansdotter (F), *Max-plus algebra för tågtidtabelläggning.* Performed at SJ. Advisor: A. Forsgren. (E217)

[T12] H. Johansson (F), *Mathematical modeling and simulation of a missile.* Performed at FOA. Advisor: X. Hu. (E200)

[T13] M. Karlsson (F), *Origin node aggregation in traffic networks.* Performed at University of Florida. Advisor: R. L. Francis/K. Svanberg. (E204)

[T14] M. Kottenauer (F), *Evaluation and testing of optimization programs for telecommunication networks.* Performed at Telia ProSoft AB. Advisor: A. Forsgren. (E211)

[T15] J. Löfmark (F), *Rope oscillation control for hoists.* Performed at ABB. Advisor: X. Hu. (E206)

[T16] F. Sandquist (E), *Analysis of the heart rate in premature children.* Performed at Texas Tech University. Advisor: C. Martin/A. Lindquist. (E201)

[T17] A. Ståludd (F), *Kreditrisker.* Advisor: T. Björk. (E215)

[T18] H. Söderlund (F), *Analys av personvagnsomlopp.* Performed at SJ. Advisor: A. Nõu. (E212)

[T19] P. Ögren (F), *Optimal vaccination patterns in structured SIR models.* Performed at Texas Tech University. Advisor: C. Martin/A. Lindquist. (E209)

5B1023 Master Thesis in Systems Engineering, 20 p (*Examensarbete i systemteknik)*

[T20] S. Abrahamsson (T), *Underhållsplanering för SAS.* Performed at SAS. Advisor: U. Brännlund. (S102)

[T21] A. Andersson (M), *Framtagning av rutiner och metoder för optimering av materialhantering i samband med tillverkning av komplexa mätsystem.* Performed at CE Johansson AB. Advisor: U. Brännlund. (S100)

[T22] A.-K. Back (T), *Aging aircraft structures - A comparison between old and new aircraft with respect to maintenance costs.* Performed at SAAB Aircraft AB. Advisor: U. Brännlund. (S107)

[T23] D. Bylander (T), *Framtagande av Maintenance Program för Boeing 737 med hjälp av matematiska metoder.* Performed at SAS. Advisor: U. Brännlund. (S105)

[T24] D. Jonasson (M), *Tidtabelläggning och simulering av tågtrafik.* Performed at Banverket. Advisor: A. Nõu. (S103)

[T25] M. Lundell (T), *Investigate methods how to use a direction of negative curvature.* Performed at Stanford University. Advisor: W. Murray/A. Forsgren. (S101)

[T26] H. Moberg (T), *Utvärdering av FBSIM-modellen.* Performed at FOA. Advisor: C. Trygger. (S106)

[T27] M. Olsson (T), *Aging aircraft systems - A comparison between old and new aircraft with respect to maintenance costs.* Performed at SAAB Aircraft AB. Advisor: U. Brännlund. (S108)

[T28] J. Palmheden (T), *Automatisk felkompensering av rörlig sensorplattform.* Performed at Celsius Tech AB. Advisor: C. Trygger. (S104)

4 Seminars at the division

- Roger J.-B. Wets, University of California, Davis, California, USA, *Variational analysis and statistical estimation*, October 12, 1998.
- Clyde F. Martin, Texas Tech University, Lubbock, Texas, USA, *Tracking, data analysis and optimal control*, December 3, 1998.
- Jöran Petersson, Mälardalen University, Västerås, *Algorithms for fitting two classes of exponential sums to empirical data*, December 4, 1998.
- Bertina Ho-Mock-Qai, Centre d'Etudes de la Navigation Aerienne, Toulouse, France, *A nonlinear approach to robust stabilization*, December 7, 1998.
- Ulf Jönsson, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA, *Computations in robustness analysis*, December 8, 1998.
- Zhaojun Bai, University of Kentucky, Kentucky, USA, *Reduced-order modeling of linear dynamical systems*, December 11, 1998.
- Jorge Marí, Adtranz, Västerås, *Identification of multivariable stochastic systems in polynomial time*, April 16, 1999.
- Danny C. Sorensen, Rice University, Houston, Texas, USA, (visiting professor at KTH, spring 1999), *Krylov projection methods for model reduction*, April 23, 1999.
- Oleg Burdakov, Linköping University, *A greedy algorithm for the optimal basis problem and its application to interpolation methods*, April 30, 1999.
- Jana Kosecka and Shankar Sastry, University of California, Berkeley, California, USA, *Multiview geometry revisited: A differential geometric approach*, May 25, 1999.
- Jana Kosecka and Shankar Sastry, University of California, Berkeley, California, USA, *Euclidean reconstruction and reprojection up to subgroups*, May 26, 1999.
- Shankar Sastry, University of California, Berkeley, California, USA, *Algorithms for the design of networks of unmanned aerial vehicles*, May 27, 1999.
- György Michaletzky, Eötvös Lorand University, Budapest, Hungary, *Stochastic approach to Nevanlinna-Pick interpolation problem*, May 29, 1999.
- Claude Lemaréchal, INRIA Rhône-Alps, Grenoble, France, *Duality without tears*, June 2, 1999.
- Claude Lemaréchal, INRIA Rhône-Alps, Grenoble, France, *Lagrangian duality and SDP relaxation in combinatorial optimization*, Seminar series, June 2–4, 1999.
- W. P. Dayawansa, Texas Tech. University, Lubbock, Texas, USA, *Lyapunov functions for switching systems*, June 4, 1999.
- Margaret H. Wright, Bell Laboratories, Murray Hill, New Jersey, USA, *Primal-dual methods: theory and practice*, June 8, 1999.
- Stephen P. Boyd, Stanford University, Stanford, California, USA, *Optimization over linear matrix inequalities*, June 24, 1999.

5 Publications

5.1 Papers in journals and books (published and accepted)

[A1] C. Altafini, *A path tracking criterion for an LHD articulated vehicle*, International Journal of Robotics Research, vol. 18, no. 5, 1999, 435-441.

[A2] C. I. Byrnes, S. V. Gusev and A. Lindquist, *A convex optimization approach to the rational covariance extension problem*, SIAM J. Control and Optimization,37 (1999), 211–229.

[A3] U. Brännlund, P. O. Lindberg, A. Nõu, and J.-E. Nilsson, *Railway timetabling using Lagrangian relaxation*, Transportation Science, 32 (1998), 358-369.

[A4] A. Dahlén, A. Lindquist and J. Marí, *Experimental evidence showing that stochastic subspace identification methods may fail*, Systems & Control Letters 34 (1998), 303-312.

[A5] M. Egerstedt and C. F. Martin, *Trajectory planning in the infinity norm for linear control systems*, To appear in International Journal of Control.

[A6] S. Feltenmark and K. C. Kiwiel, *Dual applications of proximal bundle methods including Lagrangian relaxation of nonconvex problems*, To appear in SIAM Journal of Optimization.

[A7] A. Forsgren and P. E. Gill, *Primal-dual interior methods for nonconvex nonlinear programming*, SIAM Journal on Optimization 8 (1998), 1132-1152.

[A8] P.-O. Gutman and B. Nilsson, *Modelling and prediction of bending stiffness for paper board manufacturing*, Journal of Process Control, vol. 8, no 4, 229-237, 1998.

[A9] X. Hu, *Global nonlinear feedback stabilization and nonpeaking conditions*, Automatica vol. 34, No. 11, 1998.

[A10] X. Hu and C. Martin, *Linear reachability versus global stabilization*, IEEE Trans. Auto. Control vol. 44, No. 6, 1999.

[A11] K. H. Johansson, M. Egerstedt, J. Lygeros, and S. Sastry, *On the regularization of Zeno hybrid automata*, To appear in Systems and Control Letters, Special Issue on Hybrid Systems.

[A12] K. C. Kiwiel, P. O. Lindberg and A. Nõu, *Bregman proximal relaxation of large-scale 0–1 problems*, To appear in Computational Optimization and Applications.

[A13] A. Lindquist and V. A. Yakubovich, *Universal regulators for optimal tracking in discrete-time systems affected by harmonic disturbances*, IEEE Transactions on Automatic Control, AC-44 (1999), 1688–1704.

[A14] R. Linker, I. Seginer and P.-O. Gutman, *Optimal CO2-control in a greenhouse modeled with neural networks*, Computers and Electronics in Agriculture, vol 19, 289-310, 1998.

[A15] J. Marí, A. Dahlén and A. Lindquist, *A covariance extension approach to identification of time series*, Automatica 36 (2000), to be published.

[A16] J. Marí and C. Martin, *Asymptotic output tracking with a two level hierarchical system*, International Journal of Control 72 (1999), 1116-1126.

[A17] C. F. Martin, S. Sun, and M. Egerstedt, *Optimal control, statistics and path planning*, To appear in Mathematical and Computer Modeling.

[A18] A. Matveev, X. Hu, R. Frezza and H. Rehbinder, *Observers for systems with implicit output*, To appear in IEEE Trans. Auto. Control.

[A19] H. Rotstein, N. Galperin and P.-O. Gutman, *Set membership approach for reducing value sets in the frequency domain*, IEEE Transactions on Automatic Control, vol. 43, no 9, 1346-1350, 1998.

5.2 Papers in conference proceedings (published and accepted)

[C1] C. Altafini, *Controllability and singularities in the n-trailer system with kingpin hitching* , IFAC World Congress 1999, Beijing, China, July 1999.

[C2] C. Altafini, *Curve negotiating using polar polynomials for nonholonomic vehicles*, IFAC World Congress 1999, Beijing, China, July 1999.

[C3] C. Altafini, *Following a path of varying curvature as an output regulation problem*, 1999 IEEE Mediterranean Control Conference. Haifa, Israel, June 1999.

[C4] C. Altafini, *Why to use an articulate vehicle in underground mining operations?*, 1999 IEEE International Conference on Robotics and Automation Detroit, May 1999.

[C5] C. Altafini, *The general n-trailer problem: conversion into chained form*, 37th IEEE Conference on Decision and Control, Tampa, Florida, USA, December 1998.

[C6] C. Altafini and P.-O. Gutman, *Path following with reduced off-tracking for car-like non-holonomic vehicles*, Proc. MTNS98, Mathematical Theory of Networks and Systems, July 6-10, 1998, Padova, Italy.

[C7] C. Altafini and P.-O. Gutman, *Path following with reduced off-tracking for the n-trailer system*, IEEE Conference on Decision and Control, December 1998, Tampa, Florida, USA.

[C8] M. Egerstedt and C. F. Martin, *Trajectory planning for linear control systems with generalized splines*, Proceedings of MTNS, pp. 999-1002, Padova, Italy, Jul., 1998.

[C9] M. Egerstedt, X. Hu, and A. Stotsky, *Control of a car-like robot using a virtual vehicle approach*, Proceedings of the 37th IEEE CDC, pp. 1502-1507, Tampa, Florida, USA, Dec., 1998.

[C10] M. Egerstedt, X. Hu and A. Stotsky, *A hybrid control approach to action coordination for mobile robots*, In the proc. of IFAC 1999.

[C11] M. Egerstedt, J. Koo, F. Hoffmann, and S. Sastry, *Path planning and flight controller scheduling for an autonomous helicopter*, Lecture Notes in Computer Science 1569: Hybrid Systems: Computation and Control, pp. 91-102, Berg en Dal, The Netherlands, Springer Verlag, March, 1999.

[C12] X. Hu and H. Rehbinder, *Nonlinear state estimation for rigid body motion with low-pass sensors*, Proceedings of the 7th IEEE Med. Control Conference, Haifa, Israel, June 1999.

[C13] I. Ioslovich and P.-O. Gutman, *Plant factory optimization*, Proceedings of the 3rd International Conference on Industrial Automation, 7-9 June 1999, Montreal, Canada.

[C14] I. Ioslovich and P.-O. Gutman, *Model for water distribution control: conveyance, allocation and reuse*, Proceedings of the 3rd IMACS/IFAC International Symposium on Mathematical Modelling and Simulation in Agriculture and Bio-Industries, 7-9 June 1999, Uppsala, Sweden.

[C15] A. Liberzon, D. Rubinstein and P.-O. Gutman, *Active control for single wheel suspension of off-road track vehicle*, IFAC Workshop on Motion Control, Grenoble, France, September 21-23, 1998.

[C16] R. Linker, P.-O. Gutman and I. Seginer, *Robust failure detection and identification in a greenhouse modeled with hybrid physical/neural networks models*, International Conference on Agricultural Engineering (Ag Eng Oslo 98), Oslo, Norway, August 24-28, 1998.

[C17] R. Linker, I. Seginer and P.-O. Gutman, *A comparison between different approaches for greenhouse climate modeling with neural networks*, 7th IEEE Mediterranean Conference on Control and Automation, Haifa, 28-30 June, 1999.

[C18] C. F. Martin and H. Rehbinder, *Modeling and control of the forearm*, Proceedings of the MTNS-98 Symposium, Padova, Italy, July, 1998.

[C19] J. Pettersson and P.-O. Gutman, *Automatic tuning of the window size in the Box Car Back Slope data compression algorithm*, 7th IEEE Mediterranean Conference on Control and Automation, Haifa, 28-30 June, 1999.

[C20] A. Serebrennikov and P.-O. Gutman, *A QFT design for the EDF benchmark problem*, 14th World Congress of the International Federation of Automatic Control, Beijing 5-9 July, 1999.

[C21] J. Sjöberg and P.-O. Gutman, *Non-linear identification of the position arm dynamics of a CD player*, 7th IEEE Mediterranean Conference on Control and Automation, Haifa, 28-30 June, 1999.

[C22] A. Stotsky and X. Hu, *Nonlinear/adaptive control of car-like mobile robots in a single-track dynamical model framework*, Presented at MTNS 1998, Padova, Italy, July 1998.

[C23] A. Stotsky, X. Hu, and M. Egerstedt, *Sliding mode control of a car-like mobile robot using single-track dynamic model*, Proceedings of the 5th International Workshop on Variable Structure Systems, Longboat Key, Florida, USA, Dec., 1998.

[C24] A. Stotsky, X. Hu and M. Egerstedt, *Adaptive/variable structure control of car-like mobile robot in four wheel dynamical model framework*, Proc. of CDC 1998, Tampa, USA, December, 1998.

[C25] K. Svanberg, *The Method of Moving Asymptotes for modelling and solving optimization problems*, Proceedings of the WCSMO-3, Buffalo, USA, May 1999.

[C26] A. Tiano, A. Biran A and P.-O. Gutman, *Recent developments in marine systems control*, Workshop on Offshore Technologies for Aquaculture, Technion, Haifa, Israel, October 13-16, 1998.

5.3 Other publications

[O1] U. Brännlund, *Nondifferentiable optimization: Subgradient optimization methods*, To appear in Encyclopedia of Optimization, edited by C. A. Floudas and P. M. Pardalos, Kluwer Academic Publishers.

[O2] U. Brännlund, *Nondifferentiable optimization: Relaxation methods*, To appear in Encyclopedia of Optimization, edited by C. A. Floudas and P. M. Pardalos, Kluwer Academic Publishers.

[O3] A. Forsgren, *An application of interior methods to the approximation of forward rate curves*, SIAG/OPT Views-and-News 10 (1999), 1–3.

[O4] A. Forsgren, *Equality constrained nonlinear programming: introduction, and KKT necessary optimality conditions*, To appear in Encyclopedia of Optimization, edited by C. A. Floudas and P. M. Pardalos, Kluwer Academic Publishers.

[O5] P.-O. Gutman, *Review of Adaptive Control of Systems with Actuator and Sensor Nonlinearities by G. Tao and Petar V. Kokotović*, International Journal of Adaptive Control and Signal Processing, vol. 12, no. 6, 537-538, 1998.

[O6] K. Svanberg, *Structural Optimization*, To appear in Encyclopedia of Optimization, edited by C. A. Floudas and P. M. Pardalos, Kluwer Academic Publishers.

5.4 Technical reports and preprints

[R1] C. I. Byrnes, P. Enqvist and A. Lindquist, *Cepstral coefficients, covariance lags and pole-zero models for finite data strings*, Submitted for publication.

[R2] C. I. Byrnes, T. T. Georgiou and A. Lindquist, *A new approach to Spectral Estimation: A tunable high-resolution spectral estimator*, Submitted for publication.

[R3] C. I. Byrnes, T. T. Georgiou and A. Lindquist, *Advances in high-resolution spectral estimation*, To appear in a book published in the fall of 1999 by Kluwer Academic Publishers.

[R4] C. I. Byrnes, T. T. Georgiou and A. Lindquist, *A generalized entropy criterion for Nevanlinna-Pick interpolation: A convex optimization approach to certain problems in systems and control*, Submitted for publication.

[R5] C. I. Byrnes and A. Lindquist, *On the duality between filtering and Nevanlinna-Pick interpolation*, Submitted for publication.

[R6] M. Egerstedt, X. Hu and A. Stotsky, *A hybrid control approach to action coordination for mobile robots*, Submitted to Automatica.

[R7] M. Egerstedt, X. Hu and A. Stotsky, *Control of mobile platforms using a virtual vehicle approach*, Submitted to IEEE Trans. Aut. Control.

[R8] A. Forsgren, *Optimality conditions for nonconvex semidefinite programming*, Submitted to Mathematical Programming. (Revision of report TRITA-MAT-1998-OS6).

[R9] H. Rehbinder and X. Hu, *Nonlinear state estimation for rigid body motion with low-pass sensors*, Submitted to Systems and Control Letters.

6 Presentations

[P1] C. Altafini, *Path following with reduced off-tracking for car-like nonholonomic vehicles*, MTNS Mathematical Theory of Networks and Systems, Padova, July 1998.

[P2] C. Altafini, *The general n-trailer problem: conversion into chained form*, 37th IEEE Conference on Decision and Control, Tampa, Florida, USA, December 1998.

[P3] C. Altafini, *Path following with reduced off-tracking for the n-trailer system*, 37th IEEE Conference on Decision and Control, Tampa, Florida, USA, December 1998.

[P4] C. Altafini, *Why to use an articulate vehicle in underground mining operations?*, 1999 IEEE International Conference on Robotics and Automation, Detroit, May 1999.

[P5] C. Altafini, *Following a path of varying curvature as an output regulation problem*, 1999 IEEE Mediterranean Control Conference, Haifa, Israel, June 1999.

[P6] U. Brännlund, *A serie of four lectures on truss topology design*, Universidad de la República, Montevideo, Uruguay, Aug-Sept 1998.

[P7] U. Brännlund, *Railway timetabling using Lagrangian relaxation*, CLAIO, Buenos Aires, Argentina, Aug 1998.

[P8] U. Brännlund, *Three different algorithms for solving truss topology design problems*, Invited lecture at Technical University of Denmark, Lyngby, Dec 1998.

[P9] U. Brännlund, *Optimal topology design of truss structures under multiple loadcases*, NorFa Workshop, Åre, April 1999.

[P10] U. Brännlund, *Different formulations of truss topology design problems and their merits*, Minisymposia at the SIAM 1999 Anual Meeting in Atlanta, Georgia, USA, May 14 1999.

[P11] M. Egerstedt, *Trajectory planning for linear control systems with generalized splines*, Conference on Mathematical Theory of Networks and Systems, Padova, Italy, Jul. 1998.

[P12] M. Egerstedt, *Control of a car-like robot using a virtual vehicle approach*, 37th IEEE Conference on Decision and Control, Tampa, Florida, USA, Dec. 1998.

[P13] M. Egerstedt, *Optimal path planning for linear control systems*, 37th IEEE Conference on Decision and Control, Tampa, Florida, USA, Dec. 1998.

[P14] M. Egerstedt, *Path planning and flight controller scheduling for an autonomous helicopter*, Second International Workshop on Hybrid Systems: Computation and Control, Nijmegen, The Netherlands, March 1999.

[P15] M. Egerstedt, *Behavior based mobile robotics*, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden, April 1999.

[P16] P. Enqvist, *Lattice-ladder-notch-filter design: An enhancement of linear predictive coding*, 13th Mathematical theory of networks and systems symposium, Padova, Italy, July 6-10, 1998.

[P17] S. Feltenmark, *Seasonal planning in the Nordic power system*, INFORMS Cincinnatti Spring 1999, May 2-5, 1999.

[P18] S. Feltenmark, *Head-dependent hydro power scheduling*, NTNU, Trondheim, Norway, June 8, 1999.

[P19] A. Forsgren, *Primal-dual interior methods for nonlinear and semidefinite programming*, Optimization 98 Conference, Coimbra, Portugal, July 20-22, 1998.

[P20] A. Forsgren, *Interior methods for optimization*, University of Bergen, Bergen, Norway, November 19, 1998.

[P21] A. Forsgren, *Optimality conditions for nonconvex semidefinite programming*, The 6th SIAM Conference on Optimization, Atlanta, Georgia, USA, May 10–12, 1999.

[P22] C. Landén, *Bond pricing in a regime-switching short rate model*, 13th Mathematical theory of networks and systems symposium, Padova, Italy, July 6-10, 1998.

[P23] C. Landén, *Bond pricing in a regime-switching short rate model*, The future of stochastic analysis II; workshop on stochastic analysis and related fields, KTH, Stockholm, Sweden, October 7-10, 1998.

[P24] A. Lindquist, *Experimental evidence that subspace methods may fail*, International Symposium on the Mathematical Theory of Networks and Systems, Padova, Italy, July 6–10, 1998.

[P25] A. Lindquist, *A convex optimization approach to Nevanlinna-Pick interpolation problems in robust stabilization*, Plenary lecture at the International Conference *Dynamical Systems: Stability, Control, Optimization*, Minsk; Belarus on September 28 - October 4, 1998.

[P26] A. Lindquist, *Analytic interpolation with degree constraints, with applications to systems and control*, Texas Tech University, February 24,1999.

[P27] A. Lindquist, *Analytic interpolation with degree constraints, with applications to systems and control*, Moscow University, April 7, 1999.

[P28] A. Lindquist, *Analytic interpolation with degree constraints, with applications to systems and control*, International Conference on Rational Approximation, Antwerpen, Belgium, June 7–11, 1999.

[P29] M. Prytz, *Capacity Dimensioning of Data Networks with Multicast Traffic*, 6th SIAM Conference on Optimization, Atlanta, Georgia, USA, May 10-12, 1999.

[P30] H. Rehbinder, *Modeling and control of the forearm*, MTNS-98 Symposium, Padova, Italy, July, 1998.

[P31] H. Rehbinder, *Nonlinear state estimation for rigid body motion with low-pass sensors*, 7th IEEE Med. Control Conference, Haifa, Israel, June 1999.

[P32] M. Stolpe, *A primal-dual method for sizing and topology optimization*, NorFa Workshop on Structural Optimization, Åre, April 16-18, 1999.

[P33] K. Svanberg, *A new globally convergent version of MMA*, NorFa Workshop on Structural Optimization, Åre, April 16-18, 1999.

[P34] K. Svanberg, *The Method of Moving Asymptotes for modelling and solving optimization problems*, WCSMO-3 in Buffalo, New York, USA, May 1999.

7 Other activities

Claudio Altafini

- Co-supervision of Master thesis at the Centre for Autonomous Systems, KTH: J. Grebäck (F) A kinematic approach to motion planning of a mobile manipulator
- Co-supervision of Master thesis at the Department of Signal Processing and Control, KTH: M. Parodi Backward motion control of truck with trailers: implementation issues.
- Referee for Automatica, IEEE Trans on Control System Technology, ACC'99 and CDC'99.

Ulf Brännlund

- Participated in SIAM Conference on Optimization, Atlanta, May 1999
- Visited Universidad de la Rebública, Montevideo, Uruguay, Aug-Sept 1999.
- Referee for SIAM Journal on Optimization.

Anders Dahlén

- Participated in the 8th ERNSI Workshop on System Identification in Vienna, Austria, September, 1998.

Magnus Egerstedt

- Spent seven months at University of California, Berkeley as a visiting scholar.
- Vice president of IEEE student branch at KTH.
- Referee for Autonomous Robots, Automatica, CDC'99, and IROS'99.

Per Enqvist

- Participated in the 8th ERNSI Workshop on System Identification in Vienna, Austria, September, 1998.

Torvald Ersson

- Participated in the 8th ERNSI Workshop on System Identification in Vienna, Austria, September, 1998.

Stefan Feltenmark

- Participated in VII International Conference on Stochastic Programmming, University of British Columbia, Vancouver, Canada, August 8-16, 1998.

Anders Forsgren

- Member of editorial board for *Computational Optimization and Applications*.
- External advisor at appointment of associate professor position, Linköping University, December 1998.
- External advisor at appointment of associate professor position, University of Bergen, May 1999.
- Visited the University of California, San Diego, California, USA, August 5–14, 1998.
- Referee for BIT, Mathematical Programming and SIAM Journal on Optimization.

Per-Olof Gutman

- Associate Editor for *Automatica*.
- Local arrangement chairman for the 7th IEEE Mediterranean Conference on Control and Automation, Haifa, 28-30 June, 1999 and was instrumental to make it the first control conference ever to have an official winery — the Baron Cellars - Tishbi Estate Winery, Binyamina, Israel.

Camilla Landén

- Participated in a workshop on mathematical finance at Humboldt Universität, Berlin, Germany, December 3-5, 1998.

Anders Lindquist

- Chairman, Department of Mathematics, Royal Institute of Technology.
- Vice Chairman, Appointment Committee for School of Engineering Physics (Tjänsteförslagsnämnden), KTH.
- Member Central Faculty Board ("Centrala fakultetsnmnden"), KTH.
- Board Member, Strategic Center for Autonomous Systems, KTH.
- Member of the Committee for IIASA, Systems Analysis and Risk Analysis, FRN (Swedish Council for Planning and Coordination of Research).
- Member of the Evaluation Committee for the Mathematical Sciences, NFR (Natural Science Foundation).
- Member, Royal Swedish Academy of Engineering Sciences (IVA).
- Member Editorial Board, *Adaptive Control and Signal Processing*, journal published by John Wiley & Sons.
- Editorial Board, *Applied and Computational Control, Signals, and Circuits*, book series published by Birkhäuser, Boston.
- Referee for several other journals, for NATO, STINT, KVA and Italian National Research Foundation.
- Affiliate Professor, Washington University, St Louis, USA.
- Advisory Board of the Institute for Mathematics of the Life Sciences, Texas Tech University, Texas, USA.
- Team Leader, European Research Network for System Identification (ERNSI), TMR network.
- Member, Nomination Assembly ("Elector"), Swedish Natural Science Foundation.
- Steering Committee, International Symposium on the Mathematical Theory of Networks and Systems (MTNS).
- Member, International IFAC Committee for Mathematics in Control.
- Member, Steering Committee of the ERCIM Working Group on Control and System Theory.
- Program Committee, 1998 International Symposium on the Mathematical Theory of Networks and Systems (MTNS98), Padova, Italy, July 6–10, 1998.
- International Program Committee, International Symposium on the Mathematical Theory of Networks and Systems (MTNS2000), Perpignan, France, June 19–23, 2000.
- International Advisory Committee of the 30th ISCIE International Symposium on Stochastic Systems Theory and its Applications, Kyoto, Japan, November 4–6, 1998.
- International Advisory Committee of the 31th ISCIE International Symposium on Stochastic Systems Theory and its Applications, Yokohama, Japan, November 11–12, 1999.

Ryozo Nagamune

- Participated in ERNSI Workshop, Vienna, Austria, September 28-30, 1998.

Andreas Nõu

- Referee for the proceedings book of the 6th Meeting of the EURO Working Group on Transportation, September 9-11, 1998.
- Opponent at a licentiate thesis defense, Systems and Control Group, Uppsala

University, Sweden, December 16, 1998.

- Opponent at a licentiate thesis defense, School of Mathematical and Computing Sciences, Chalmers University of Technology, Sweden, April 23, 1999.

Mikael Prytz

- Participated in the international workshop "Semidefinite Programming: Applications and Algorithms," ZIB, Berlin, Germany, Nov 15 - 17, 1998.
- Participated in the international conference "Approximation and Complexity in Numerical Optimization: Continuous and Discrete Problems," University of Florida, USA, Feb 28 - March 2, 1999.

Henrik Rehbinder

- Participated in the ARTES Summer School'98, Lidingö, Sweden, August 17-21, 1998.

Göran Sporre

- Participated in the 6th SIAM Conference on Optimization, Atlanta, Georgia, USA, May, 1999.

Krister Svanberg

- On the editorial board of Structural Optimization.
- Referee for International Journal for Numerical Methods in Engineering.
- Referee for ASCE Journal of Structural Engineering.