KTH Mathematics

Activity Report 2003/2004

Division of Optimization and Systems Theory
Department of Mathematics
Royal Institute of Technology
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http://www.math.kth.se/optsyst/

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 2003/2004 (July 2003 – June 2004).

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 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.

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1 Personnel

1.1 List of personnel

Faculty

Ulf Brännlund, senior lecturer
Anders Forsgren, professor
Xiaoming Hu, professor
Anders Lindquist, professor, head of division
Krister Svanberg, associate professor, director of undergraduate studies
Claes Trygger, senior lecturer

Research associate (Forskarassistent)

Ulf Jönsson, docent

Postdoctoral fellow (Postdoktorstipendiat)

Chung-Yao Kao, PhD

Guest researchers (Gästforskare)

Hisaya Fujioka, associate professor
Per-Olof Gutman, associate professor

Administratör (Administrator)

Erika Appel

Graduate students (Doktorander)

Stefan Almér, civing
David A. Anisi, civing (since January 2004)
Anders Blomqvist, civing
Gianantonio Bortolin
Fredrik Carlsson, civing
Vanna Fanizza
Christelle Gaillemard
Tove Gustavi, civing
Maja Karasalo, civing (since May 2004)
Johan Karlsson, civing (since August 2003)
Mats Werme, civing

1.2 Biographies

Stefan Almér received the degree of civilingenjör in Engineering Physics from KTH in 2003. He spent the academic year 2000-2001 as an exchange student at ETH Zuerich, Switzerland. Since February 2003 he is a graduate student at the Division of Optimization and Systems Theory. He is currently doing research on stability of pulse-width modulated systems with applications in power electronics.

David A. Anisi was born in Tehran, Iran, in 1977. He received a civilingenjör degree in Engineering Physics from KTH in 2003. The academic year of 2000-2001, was spent as an exchange student in Houston, USA. His Master's thesis was carried out at the Swedish Defence Research Agency (FOI) and exploited the optimal motion control of a ground vehicle. Currently, he is a Ph.D. student at the Division of Optimization and Systems Theory at KTH, where he is working on a joint research project with FOI. His main research interests are in optimal path planning and nonlinear control of robotic systems.

Erika Appel has been administrator at the Division of Optimization and Systems Theory since 2000.

Anders Blomqvist was born in Täby, Sweden, in 1976. He received a civilingenjör degree in Engineering Physics from KTH in 2001. He spent the academic year 1999-2000 as an exchange student at Washington University in St. Louis. Since the spring of 2001 he is a graduate student at the Division of Optimization and Systems Theory. His research involves analytic interpolation theory with a complexity constraint and its applications in systems and control.

Gianantonio Bortolin was born in Pordenone, Italy, in 1973. He received his degree in Electrical Engineering in 1999 from University of Padova. He did his undergraduate thesis in 1999 at Scania with KTH. Presently he is a PhD student at the Division of Optimization and Systems Theory and cooperates in a project on "Process modelling, operator training simulation, and optimization applied to a paper board manufactoring" at AssiDomän Cartonboard AB.

Ulf Brännlund 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. He is chairman of the board and cofounder of the company Optimization Partner Stockholm AB (www.optimizationpartner.com). His main research interests are nondifferentiable optimization, semidefinite programming and structural optimization.

Fredrik Carlsson was born in Halmstad, Sweden, in 1978. He received his MSc degree in Engineering Physics from Chalmers University of Technology in 2002. He spent the academic year 2001-2002 as an exchange student at Imperial College in London and did his master thesis at Hewlett-Packard Labs in Palo Alto, USA. Since the spring of 2003 he is a graduate student at the Division of Optimization and Systems Theory. His research project, performed in collaboration with RaySearch Medical AB, focus on studying and developing optimization algorithms for intensity modulated radiation therapy.

Vanna Fanizza was born in Conversano, South of Italy, in 1975. She received a degree in Mathematics from University of Bari. She gots a schoolarship in Math Dept, University of Milano Bicocca from 1999 to 2000. She was employed in Ericsson Telecomunicazioni S.p.A, Italy from 2000 to 2001. Since the fall of 2001 she is a graduate student at the Division of Optimization and Systems Theory. Her research interest is the identification of positive real linear system via orthonormal basis and Nevanlinna-Pick interpolation with complexity constraint for the MIMO case.

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 2003 he is a 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.

Hisaya Fujioka was born in Japan, in 1967. He received the B.E., M.E., and Ph.D. degrees all from Tokyo Institute of Technology, Japan, in 1990, 1992, and 1995, respectively. He served as a research associate at the Faculty of Engineering, Osaka University, Japan, in 1995–1997. Since 1998 he is an associate professor at the Graduate School of Informatics, Kyoto University, Japan. His current research interests include sampled-data control, robust control, networked control systems, and computer-aided control systems design.

Christelle Gaillemard was born in Cholet, France, in 1978. She received her degree in Mechanical Engineering with a specialisation in automatic control, in June 2001 at ESSTIN in Nancy, France. She did her master thesis in 2001 at AssiDomän Frövi AB, Sweden. Currently she is a PhD student at the Division of Optimization and Systems Theory and her project in collaboration with AssiDomän Frövi AB consists of modelling the moisture content of a four layers papersheet using grey-box modelling and identification.

Tove Gustavi was born in Tumba, Sweden, in 1977. She received her M.Sc. in Engineering Physics from KTH, Stockholm, in 2001. 2001-2002 she worked as development engineer in optical communication. Since 2003 she is a graduate student at the Division of Optimization and Systems Theory. Her main area of research is motion planning for mobile robots, including path-following, tracking and formation planning.

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 Technion — Israel Institute of Technology, Haifa, where he is currently an Associate Professor at the Faculty of Civil and Environmental Engineering.

Since 1990 he spends two—three months a year as a guest researcher at the Division of Optimization an Systems Theory, Royal Institute of Technology, Stockholm, Sweden, where he has served as an advisor for several students. He was a Visiting Professor at the Laboratoire d'Automatique de Grenoble, France, 1995-96. Gutman served on the editorial board of Automatica 1997 - 2002.

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.

Ulf Jönsson was born in Barsebäck Sweden. He received the M.Sc. degree in Electrical Engineering in 1989 and the Ph.D. degree in Automatic Control in 1996, both from Lund Institute of Technology, Lund, Sweden.
He spent the academic year 1989-1990 at the Department of Electrical Engineering at University of California, Santa Barbara. In the first half of 1997 he was a postdoctoral fellow at California Institute of Technology and thereafter he had a two year appointment as a postdoctoral fellow at the Laboratory for Information and Decision Systems, Massachusetts Institute of Technology. He has been with the Division of Optimization and Systems Theory at the Royal Institute of Technology since 1999. He was appointed Docent in the spring 2002 and he is an associate editor for IEEE Transactions on Automatic Control since 2003.
His current research interests include design and analysis of nonlinear and uncertain control systems, periodic system theory, switched dynamical systems, and optimization applications in systems theory.

Chung-Yao Kao was born in Tainan, Taiwan. He received the Sc.D. degree in mechanical engineering from Massachusetts Institute of Technology, Cambridge, MA, USA in 2002. From September 2002 to June 2003, he held research positions at the Department of Automatic Control of the Lund Institute of Technology, Lund, and at the Mittag-Leffler Institute, Djursholm, in Sweden. He is currently a postdoctoral research associate with the Division of Optimization and Systems Theory at the Royal Institute of Technology, Stockholm, Sweden.
His research interests include analysis and design of complex dynamical systems, specialized fast computational algorithms for control system analysis and synthesis, and control system applications.

Maja Karasalo was born in 1979. She recieved a civilingenjör degree in Engineering Physics from KTH in 2004. She wrote her master's thesis at the Centre for Biocybernetics and Intelligent Systems at Washington University in St Louis. Since May 2004 she is a graduate student at the Division of Optimization and Systems Theory and at the Centre of Autonomous Systems. Her main area of research is motion planning and mobile manipulation.

Johan Karlsson was born in Stockholm, Sweden, 1979. He received his Master of Science in Engineering Physics from KTH, Stockholm, in 2003. He spent the academic year 2000-2001 as an exchange student at Washington University in Saint Louis, USA, and did his master thesis at University of Minnesota in Minneapolis, USA. Since August 2003 he is a graduate student at the Division of Optimization and System Theory at KTH. His research interest involves analytic interpolation, distance measures and uncertainty for speech processing and signal analysis.

Yohei Kuroiwa was born in Kanagawa, Japan, in 1978. He received his B.S. degree in Mechanical and Aerospace Engineering from Tohoku University in 2001 and M.S. degree in Complexity Science and Engineering from the University of Tokyo in 2003. Currently he is a PhD student at the Division of Optimization and Systems Theory.

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, the Russian Academy of Sciences, Moscow, East China Normal University, Shanghai, Technion, Haifa, Israel, and University of California at Berkeley.
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 of Engineering Sciences, a Foreign Member of the Russian Academy of Natural 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), an Advisory Board

Member of the Institute for Mathematics of the Life Sciences, Texas Tech University, and a member of the Board of Governors of the Israel Institute of Technology (Technion) in Haifa. For the first half of 2003, he served as the scientific leader at Institut Mittag-Leffler.
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 biennial international symposia on the Mathematical Theory of Networks and Systems (MTNS).

Krister Svanberg was born in Stockholm in 1950. In 1975 he got his Civilingenjör degree in Engineering Physics, in 1982 he got his TeknD degree in Optimization Theory, and 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. 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.

Mats Werme was born in Uppsala, Sweden, in 1976. In 2001 he received a M. Sc. in Mechanical Engineering from KTH. Since 2003 he is a PhD student at at the Division of Optimization and Systems Theory. The research deals with optimal design of load-carrying mechanical structures.

1.3 Visiting and interacting scientists

- Professor Christopher I. Byrnes, Department of Systems Science and Mathematics, Washington University, St. Louis, Missouri, USA
- Professor Daizhan Cheng, Institute of Systems Science, Chinese Academy of Sciences, Beijing, China
- Professor Tryphon T. Georgiou, Department of Electrical and Computer Engineering, University of Minnesota, Minneapolis, Minnesota, USA
- Professor Bijoy K. Ghosh, Department of Systems Science and Mathematics, Washington University, St. Louis, Missouri, USA
- Professor Philip E. Gill, Department of Mathematics, University of California, San Diego, La Jolla, California, USA
- Dr. Johan Hamberg, Department of Autonomous Systems, Swedish Defence Research Agency, Stockholm, Sweden.
- Luigi Iannelli, Dipartimento di Informatica e Sistemistica, Università degli Studi di Napoli "Federico II", Napoli, Italy
- Docent Karl H. Johansson, Department of Signals, Systems and Sensors, KTH
- Dr. Johan Löf, RaySearch Laboratories AB, Stockholm, Sweden
- Dr. Jorge Marí, Bombardier Transportation, Västerås, Sweden
- Professor Clyde F. Martin, Department of Mathematics, Texas Tech University, Lubbock, Texas, USA
- Professor Alexandre Megretski, Laboratory for Information and Decision Systems, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA.
- Professor György Michaletzky, Department of Probability Theory and Statistics, Eötvös Lorand University, Budapest, Hungary
- Dr. Ryozo Nagamune, Department of Mechanical Engineering, University of California, Berkeley
- Professor Giorgio Picci, Department of Electronics and Informatics, University of Padova, Padova, Italy
- Professor Anders Rantzer, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden.
- Dr. Henrik Rehbinder, RaySearch Laboratories AB, Stockholm, Sweden
- Professor Shankar Sastry, Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, USA
- Professor Francesco Vasca, Dipartimento di Ingegneria, Università del Sannio in Benevento, Benevento, Italy
- Professor Vladimir Yakubovich, St. Petersburg State University, St. Petersburg, Russia
- Docent Yishao Zhou, Department of Mathematics at Stockholm University, Stockholm, Sweden

1.4 Networks

- Design and Engineering of the Next Generation Internet (EuroNGI), an EU Network of Excellence.
- European Research Consortium for Informatics and Mathematics (ERCIM): Working Group on Control and System Theory
- European Research Network for Systems Identification (ERNSI)
- Hybrid Control: Taming heterogeneity and complexity of networked embedded systems (HYCON)
- NorFa Network on Structural Optimization.
- Real-time Embedded Control of Mobile Systems with Distributed Sensing (RECSYS)
- Strategic Research Consortium of Autonomous Systems, KTH

2 Research

2.1 List of projects

- Control and sensing of nonlinear mobile systems
- Generalized interpolation in H^∞ with a complexity constraint
- Generalized moment problems with complexity constraints
- Geometric theory of linear stochastic systems
- Hybrid control of autonomous system
- Integral quadratic constraints
- Interior point solutions of variational problems
- Large-scale nonlinear optimization
- Optimization of radiation therapy
- Process modelling, operator training simulation and optimization applied to paper board manufacturing
- Rational Nevanlinna-Pick interpolation with degree constraints
- Real-time embedded control of mobile systems with distributed sensing
- Robust control along trajectories
- Switched dynamical systems
- Topology optimization of load-carrying structures

2.2 Description of projects

Control and sensing of nonlinear mobile systems

Researchers: Xiaoming Hu, B. Ghosh (Washington University) and C.F. Martin (Texas Tech. Univ.).

Sponsor: The Swedish Research Council (VR).

Complex control systems such as autonomous mobile systems are in general multi-behavior control systems. In many applications, they also need to operate in a team. In such cases, they are also multi-agent systems. An integral part in the design and operation of autonomous systems is control and sensing. Both are difficult problems in a realistic environment and for a realistic mobile system. Viewing such an embedded system as a set of concurrent sensor-actuator subsystems leads to the conclusion that sensory data processing forms a dual and equally important part as control actuation. For mobile systems in unknown environments, the sensing problems tend to be particularly challenging, for example, the problem of observing and mapping the structure of a dynamic environment.

To summarize, in this project we would study several issues on the integration of sensing, modeling and control. They include: model abstraction for control and sensing, active sensing, sensor fusion for input reconstruction, simultaneous localization and mapping in a continuous environment, control of multi-agent and/or multi-behavioral systems. Methods proposed here are strongly motivated from systems and control theory.

Generalized interpolation in H^∞ with a complexity constraint

Researchers: Anders Lindquist in cooperation with C. I. Byrnes (Washington University, St Louis), T. T. Georgiou (University of Minnesota) and A. Megretski (MIT).

Sponsors: The Swedish Research Council (VR) and the Göran Gustafsson Foundation.

In a seminal paper, Sarason generalized some classical interpolation problems for H^∞ functions on the unit disc to problems concerning lifting onto H^2 of an operator T that is defined on $K = H^2 \ominus \phi H^2$ (ϕ is an inner function) and commutes with the (compressed) shift S. In particular, he showed that interpolants (i.e., $f \in H^\infty$ such that $f(S) = T$) having norm equal to $\|T\|$ exist, and that in certain cases such an f is unique and can be expressed as a fraction $f = b/a$ with $a, b \in K$. In [A6], we study interpolants that are such fractions of K functions and are bounded in norm by 1 (assuming that $\|T\| < 1$, in which case they always exist). We parameterize the collection of all such pairs $(a, b) \in K \times K$ and show that each interpolant of this type can be determined as the unique minimum of a convex functional.

Our motivation stems from the relevance of classical interpolation to circuit theory, systems theory and signal processing, where ϕ is typically a finite Blaschke product, and where the quotient representation is a physically meaningful complexity constraint. These are the problems we study in the project *Rational Nevanlinna-Pick interpolation with degree constraints*. We generalize this to the case of arbitrary inner functions by first constructing on a certain set a differential form which is exact (in an appropriate sence) and which gives rise intrincically to a convex optimization problem. Indeed, or method of proof reposes on a rigorous treatment of nonlinear optimization on certain (nonreflexive) Banach spaces.

Generalized moment problems with complexity constraints

Researchers: Anders Lindquist, Anders Blomqvist and Vanna Fanizza in cooperation with C. I. Byrnes (Washington University, St Louis).

Sponsors: The Swedish Research Council (VR) and the Göran Gustafsson Foundation.

In [R4][A5] we derived a universal solution to the generalized moment problem, with a nonclassical complexity constraint, obtained by minimizing a strictly convex nonlinear functional. This generalizes some the results in the project *Rational Nevanlinna-Pick interpolation with degree constraints* to the more general setting of generalized moment problems. Moreover, some connections to probability and statistics are being pursued. In another direction, these results are being applied to systems identification using orthogonal basis function expansions. This solves the long-standing problem of how to incorporate positivity constraints in identification with orthonormal basis functions.

In [A4] the generalized moment problem with complexity constraints is studied in the case where the actual values of the moments are uncertain. This is also interpreted in terms of minimizing the Kullback-Leibler divergence for the generalized moment problem.

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 (VR) 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 geometric 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 considered.

Hybrid control of autonomous system

Researchers: Anders Lindquist, Xiaoming Hu, Simon Cedervall and Maja Karasalo.

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

This project is part of an ongoing 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 complex systems such as autonomous systems. In particular, the following issues are studied.

1. Hierarchical control architechtures for autonmous systems.
2. Sensor fusion, active sensing and nonlinear observers.
3. Feedback Control under sensor and communication constraints.
4. Path following, mobile manipulation and multi-agent control.

Integral quadratic constraints

Researchers: U. Jönsson, in cooperation with A. Megretski (M.I.T), A. Rantzer (Lund Institute of Technology, C-Y Kao (LTH and the Mittag Leffler Institute).

We are involved in an effort to develop the framework of Integral Quadratic Constraints (IQCs) for robustness analysis of uncertain and nonlinear systems. The main idea behind this framework is to use a convex set of quadratic forms (IQC) to characterize uncertainty, nonlinearities, disturbance signals and other hard-to-handle components. The analysis results in a convex optimization problem involving the nominal dynamics and the convex set of IQCs. It is applicable for analysis of general complex networked systems. We have contributed to theory development, development of IQC characterizations of several uncertainty classes, computational theory, algorithm development, and to software development. Some recent contributions are the paper [C24] presenting the software package IQCbeta [O1] and the paper [A16] presenting an efficient cutting plane algorithm for IQC optimization.

Interior point solutions of variational problems

Researchers: Anders Lindquist in cooperation with C. I. Byrnes (Washington University, St Louis).

Sponsors: The Swedish Research Council (VR) and the Göran Gustafsson Foundation.

Variational problems and the solvability of certain nonlinear equations have a long and rich history beginning with calculus and extending through the calculus of variations. We have studied "well-connected" pairs of such problems which are not necessarily related by critical point considerations. We have also studied constrained problems of the kind which arise in mathematical programming as well as constraints of a geometric nature where a solution is sought on a leaf of a foliation. In these cases we are interested in interior minimizing points for the variational problem and in the well-posedness (in the sense of Hadamard) of solvability of the related systems of equations. We have proved a general result which implies the existence of interior points and which also leads to the development of certain generalization of the Hadamard-type global inverse function theorem, along the theme that uniqueness quite often implies existence. This result has been illustrated by proving the non-existence of shock waves for certain initial data for the vector Burgers' equation, by a geometric analysis of the existence of interior points for linear programming

problems, and by a derivation of the existence of positive definite solutions of matrix Riccati equations without first analyzing the nonlinear matrix Riccati differential equation.

Large-scale nonlinear optimization

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

Sponsor: The Swedish Research Council (VR).

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 research has been directed towards interior methods for nonlinear optimization, in particular linear algebra issues related to such methods.

Optimization of radiation therapy

Researchers: Fredrik Carlsson and Anders Forsgren, in cooperation with Johan Löf (RaySearch Laboratories AB) and Henrik Rehbinder (RaySearch Laboratories AB).

Sponsors: The Swedish Research Council (VR) and RaySearch Laboratories AB.

This is an industrial graduate student project, carried out jointly between RaySearch Laboratories AB and the Division of Optimization and Systems Theory, Department of Mathematics, KTH. The specific goal of the project is to develop tailored optimization tools that are suitable for optimization problems that arise within radiation therapy. In addition, we intend to look at the biological models used and the formulations of the optimization problems that arise.

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

Researchers: Per-Olof Gutman, Anders Linquist, Xiaoming Hu, Gianantonio Bortolin, Christelle Gaillemard in cooperation with Bengt Nilsson (AssiDomän Cartonboard AB).

Sponsors: AssiDomän Cartonboard AB.

The project was funded by Vinnova from April 1999 until December 2001, and has continued thereafter with external support from AssiDomän Cartonboard AB, only. In November 2002 Gianantonio Bortolin completed his licentiate thesis on modelling and estimation of curl and twist in multi-ply paperboard (Bortolin, 2002) and is now continuing his doctoral research. Christelle Gaillemard models the drying section, and the moisture content of a four layers papersheet using grey-box modelling and identification, using Modelica for simulation.

Rational Nevanlinna-Pick interpolation with degree constraints

Researchers: Anders Lindquist, Anders Blomqvist , Vanna Fanizza, Yohei Kuroiwa and Johan Karlsson in cooperation with C. I. Byrnes (Washington University, St Louis), T. T. Georgiou (University of Minesota), and R. Nagamune (UC Berkeley).

Sponsors: The Swedish Research Council (VR) and the Göran Gustafsson Foundation.

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 and developed algorithms for determining them. This work was initiated in a joint paper by Byrnes, Georgiou and Lindquist, for which they were awarded the 2003 George S. Axelby Outstanding Paper Award. In [A2] the theory is generalized to the matrix-valued case, parameterizing a class of interpolants consisting of "most interpolants" of no higher degree than the central solution in terms of spectral zeros.

In his thesis, Nagamune applied these principles to sensitivity shaping in robust H^∞ control and to robust regulation with robust stability. Together with Nagamune, Blomqvist and Fanizza have continued this work and developed alternative algorithms that seem to be computationally more reliable [C6].

In [A9] the theory is generalized in the context of minimizing a Kullback-Leibler type distance between spectral density functions of stationary stochastic processes, and Blomqvist and Nagamune have developed a unifying algorithm for solving this optimization problem. The distance criterion in [A9] can also be used to approximate spectral densities. Johan Karlsson has undertaken a preliminary study on spectral estimation and distortion measures in speech processing within the general paradigm described above.

Real-time embedded control of mobile systems with distributed sensing

Researchers: Anders Lindquist, Xiaoming Hu, Ulf Jönsson and Tove Gustavi.

This is a joint EU project with several partners. The goal of the project is to develop methodologies and unifying principles for the rational design of embedded systems with distributed and heterogeneous sensors operating in an uncertain and changing environment. This implies that fundamental issues in the design of such embedded systems include modeling, verification, data processing from distributed and heterogeneous sensors, as well as design of concurrent controllers under sensory and communication constraints should be addressed. These research problems present the core of this project and four workpackages are accordingly organized.

Robust control along trajectories

Researchers: U. Jönsson in cooperation with C. Martin (Texas Tech), A. Megretski (M.I.T) C.-Y. Kao.

Sponsor: The Swedish Research Council (VR).

This project considers a wide range of topics related to the design and analysis of trajectories for uncertain systems. Our work has focused on three topics. The first is reach set computation for uncertain systems. This is the problem of computing the set of states that can be reached by an uncertain system and it is a crucial tool

when verifying that a hybrid system operates properly. The second topic is robustness analysis of periodic trajectories. We are here interested in deciding whether a periodic solution remains and if it stays stable in a neighborhood of the nominal solution when the system dynamics is perturbed. We consider this problem for autonomous as well as non-autonomous systems. The third topic is planning of trajectories and synthesis of robust control laws for these trajectories. Here we combine ideas from dynamic programming and optimal control to design control laws to plan trajectories that interpolate predefined regions in the state space.

Switched dynamical systems

Researchers: S. Almér, U. Jönsson, and C.-Y. Kao in collaboration with H. Fujioka, Kyoto University, L. Iannelli, University of Napoli Federico II, K. H. Johansson, KTH, J. Mari, Bombardier Transportion, F. Vasca, Universitá del Sannio in Benevento.

Sponsor: Part of this work will be sponsored within the EU NoE HYCON.

In this project we consider various problems in switched and hybrid systems. We are currently focusing on two problem areas in this field. The first is averaging theory for switched dynamical systems subject to external excitation. High frequency control signals and averaging theory is used in many control applications. The idea is that a systematic high frequency variation of the vector field can improve the controllability and simplify the control design. Averaging theory for discontinuous systems have been restricted to systems with particular nonlinearities and/or excitation signals. We are considering a general class of switched systems subject to excitation signals with Lipschitz continuous amplitude distribution function.

The second area is the design and analysis of pulse width modulated (PWM) control systems. Here we consider applications, such as switched DC-DC converters in high power applications, where averaging theory does not provide a sufficiently good approximation of the system dynamics to allow accurate design and analysis. This is an interesting class of switched systems where the switching is periodic but with varying duty rate, i.e. the proportion in which the different dynamics are active is varying from one period to another. We have recently obtained analysis results for such systems and we are working on control design.

Topology optimization of load-carrying structures

Researchers: Krister Svanberg and Mats Werme.

Sponsor: The Swedish Research Council (VR).

The purpose of this project is to develop mathematical models and efficient numerical methods for optimizing the topology and shape of load-carrying structures. During the year, we have developed a hierarchical neighbourhood search method for solving topology optimization problems defined on discretized continuum structures. The topology is represented by binary design variables indicating material or void in the various finite elements. The "engine" of the method is an efficient exploitation of the fact that if only one element is changed (from material to void or from void to material) then the new global stiffness matrix is just a low rank modification of the old one. To further speed up the process, the method is implemented in a hierarchical way. Starting from a coarse finite element mesh, the neighbourhood search is repeatedly applied on finer and finer meshes.

3 Education

3.1 Undergraduate courses

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

Instructor: Krister Svanberg.

Assistants: Stefan Almér 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.

Assistant: Stefan Feltenmark.

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: Gianantonio Bortolin.

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: Claes Trygger.

Assistant: Stefan Feltenmark and Tove Gustavi.

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.

5B1760 Linear and Quadratic Optimization, 4 p (*Linjär och kvadratisk optimering)*

Instructor: Krister Svanberg.

Assistant: Stefan Almér, Tove Gustavi, Johan Karlsson and Mats Werme.

The course should deepen the knowledge in linear algebra and give basic knowledge about optimization. In particular, the course deals with linear programming (LP) and quadratic programming (QP), where linear algebra is the main mathematical tool.

5B1814 Applied Mathematical Programming—Linear Problems, 4 p
(*Tillämpad matematisk programmering—linjära problem)*

Instructor: Anders Forsgren.

Assistant: Ulf Jönsson.

The course should deepen and broaden the theoretical, methodological and modeling knowledge in linear and integer programming. Some subjects dealt with in the course are: Interior point methods for linear programming, stochastic programming, Lagrangian relaxation for integer programming, subgradient optimization. The modeling part of the course 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.

5B1816 Applied Mathematical Programming—Nonlinear Problems, 4 p
(*Tillämpad matematisk programmering—ickelinjära problem)*

Instructor: Anders Forsgren.

The course should deepen and broaden the theoretical, methodological and modeling knowledge in nonlinear programming. Some subjects dealt with in the course are: Interior point methods for nonlinear programming, quadratic programming, SQP methods for nonlinear programming and semidefinite programming. The modeling part of the course 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.

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

Instructor: Xiaoming Hu.

Assistant: Christelle Gaillemard.

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: Mats Werme.

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.

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.

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, oligopoly and monopoly.

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

Instructor: Ulf Jönsson.

The course gives knowledge in the theory of optimal control. Some subjects dealt with in the course are: The Pontryagin maximum principle, dynamic programming in discrete and continuous time, the Hamilton-Jacobi-Bellman equation and numerical methods for solving optimal control problems.

3.2 Graduate courses

5B5766 Robust Control Theory, 6 p

Instructors: Ulf Jönsson and Chung-Yao Kao.

This is a course on modern robust control theory. Robust control has been one of the most active areas within the systems and control field since the late 1970s. It deals with uncertain systems. The motivation for using uncertain system models is that most physical systems are too complicated to be exactly represented by a single tractable mathematical model. Instead various types of uncertain linear operators are introduced in the model to capture the effects of nonlinear terms, high order unmodeled dynamics, and time-variations due to changing operating conditions. We will cover several of the main directions of robust control. The emphasis of the course will be on the latest developments based on convex optimization at the same time as we convey the basic principles at core of the subject.

5B5770 Nonlinear Systems Analysis, 5 p

Instructor: Xiaoming Hu.

This course is a basic course on nonlinear dynamical systems, presented from systems and control point of view. The main difference from the course Introduction to Nonlinear ControlSystems is: in that course, the synthesis or control design of nonlinear control systems is emphasized; and in this course, the analysis tools are studied. we plan to cover a range of topics on nonlinear systems such as approximation methods, periodic solutions, Liapunov stability, input-output stability and nonsmooth systems.

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.

5B5768 Sampled Data Control Theory, 2 p

Instructor: Hisaya Fujioka.

This is a mini course on the modern sampled-data control theory. By sampled-data system we mean an interconnection of continuous-time and discrete-time systems through analog-to-digital and digital-to-analog converters. Our main target is digital control systems, however, a lot of engineering systems including digital communication systems are sampled-data systems. The signals of interest in sampled-data systems are usually continuous-time signals and hence we will evaluate the performance based on continuous-time signals. This is a main difference from the classical discrete-time control theory. We will cover analysis and synthesis methods for sampled-data systems those are counterparts of H_2- and H_∞-control theory for continuous-time systems.

3.3 Master theses (*Examensarbeten)*

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

[T1] M. Andersson (F), *Analys av önskemålsmodell för bemanningsplanering.* Performed at Green Cargo AB. Advisor: A. Forsgren. (E281)

[T2] D. Anisi (F), *Optimal motion control of a ground vehicle.* Performed at FOI. Advisor: X. Hu. (E266)

[T3] M. Barenthin (F), *Optimal trajectories for a milking robot arm.* Performed at DeLaval International AB. Advisor: U. Jönsson. (E272)

[T4] J. Bascur (F), *Optimal temperaturprofil för extruder EP150.* Performed at ABB HVC AB. Advisor: U. Jönsson. (E268)

[T5] M. Belin (F), *Hedge optimizing in an equity portfolio that includes derivatives.* Performed at Front Capital Systems. Advisor: C. Trygger. (E269)

[T6] A. Bäckman (F), *Optimization flow control in telecommunications networks*. Performed at KTH. Advisor: A. Forsgren/U. Jönsson. (E270)

[T7] L. Carme (F), *Delivery optimization from factory to customer under charge constraints*. Performed at Saint-Gobain Recherche, Paris. Advisor: A. Forsgren. (E279)

[T8] S. Ehrlund (D), *A hybrid genetic algorithm using unified tabu search for a problem of workforce management*. Performed at Politecnico di Torino. Advisor: Krister Svanberg. (E280)

[T9] T. Fahlberg (F), *Trajectory planning using optimal control*. Performed at KTH. Advisor: C. Martin/U. Jönsson. (E264)

[T10] A. Grip (F), *Momentreglering för skruvdragarsystem*. Performed at Atlas Copco. Advisor: X. Hu. (E267)

[T11] A. Gustafsson (E), *Decentralized multi-agent coordination*. Performed at Georgia Institute of Technology. Advisor: M. Egerstedt/X. Hu. (E275)

[T12] C. Johansson (F), *Analysis of ECN/AQM schemes*. Performed at KTH. Advisor: C.-Y. Kao/U. Jönsson. (E274)

[T13] L.-M. Johansson (F), *An integrated approach to navigation of mobile robots in partially unknown environments*. Performed at Centre for Autonomous Systems. Advisor: X. Hu. (E278)

[T14] M. Karasalo (F), *Visual localization of a moving sound source*. Performed at Washington University. Advisor: B. Ghosh/X. Hu. (E282)

[T15] A. Lind (F), *Failure detection in coronary arteries of infants*. Performed at Texas Tech University. Advisor: C. Martin/U. Jönsson. (E271)

[T16] E. Lindahl (F), *Det planerade och det oplanerade underhållets påverkan på tågflödet*. Performed at Green Cargo AB. Advisor: C. Trygger. (E265)

[T17] E. Lindgren (F), *Optimal gröntidsfördelning i signalreglerade korsningar*. Performed at Trivector Traffic AB. Advisor: C. Trygger. (E273)

[T18] H. Lucien (F), *Viability of an electrical interconnection between Argentina and Chile*. Performed at Total. Advisor: U. Brännlund. (E286)

[T19] E. Lögdberg (E), *A quadratic programming approach to radiation therapy treatment planning problems*. Performed at University of Florida. Advisor: E. Romeijn/A. Forsgren. (E283)

[T20] E. Sandling (F), *Optimization of a batch pulp cooking plant*. Performed at Metso Paper. Advisor: A. Forsgren. (E284)

[T21] A. Svensson (F), *SLAM based on lines through a relative map*. Performed at EPFL Lausanne. Advisor: X. Hu. (E277)

[T22] H. Westerblad (F), *Planering av kollipackning inom pappersindustrin*. Performed at Pepto Systems. Advisor: C. Trygger. (E276)

[T23] M. Westin (F), *Optimering av lagerlängder för balkar och hålprofiler*. Performed at Tibnor. Advisor: S. Feltenmark. (E285)

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

[T24] N. de Besche and J. Ekesiöö, *Importance sampling implemented in Monte Carlo - An efficient method for simlating credit exposure of OTC derivatives.* Performed at Föreningssparbanken. Advisor: U. Brännlund. (S167)

[T25] K. Grufman, *Optimering av arkmaskinbredd.* Performed at Iggesund Paperboard. Advisor: U. Brännlund. (S166)

[T26] J. Jenevall, *Volume calculation of colour gamuts of measured L*a*b*-values.* Performed at STFI. Advisor: U. Brännlund. (S161)

[T27] N. Johansson, *Generering av scenarier för stokastiska planeringsproblem för vattenkraftproduktion.* Performed at Optimization Partner. Advisor: U. Brännlund. (S164)

[T28] A. Lundh, *Modell för korttidsoptimering av fjärrkyleproduktion i Stockholm.* Performed at Fortum Värme. Advisor: U. Brännlund. (S165)

[T29] J. Lögdström, *Spare parts optimization for a liner fleet.* Performed at Walleniusrederierna. Advisor: K. Svanberg. (S162)

[T30] E. Sidenbladh, *A study on off time deliveries at flow control center core networks.* Performed at Ericsson. Advisor: C. Trygger. (S163)

[T31] M. Örnsten and O. Marcusson, *Systemstudie av SK60 Advanced Trainer—simulerade taktiska funktioner och livscykelkostnad.* Performed at SAAB, Linköping. Advisor: U. Brännlund. (S160)

4 Seminars at the division

- Yinyu Ye, Stanford University, *Interior point methods and applications*, August 22, 2003.
- Per-Olof Gutman, Technion, *On the botanic model of plant growth with intermediate vegetative/reproductive stage*, September 15, 2003.
- Yutaka Yamamoto, Kyoto University, *Signal processing via sampled-data control theory*, September 16, 2003.
- Mikael Rönnqvist, Linköping University, *Optimization in forestry - some applications*, November 14, 2003.
- Per-Olof Gutman, Technion, *On smooth optimal control determination*, February 20, 2004.
- Ragnar Wallin, Linköping University, *Efficiently solving semidefinite programs originating from the Kalman-Yakubovich-Popov lemma using general purpose SDP solvers*, March 12, 2004.
- Moritz Diehl, University of Heidelberg, *Real-time optimization of large scale systems*, March 19, 2004.
- Clyde F. Martin, Texas Tech. University, *How many robots can talk at the same time?*, April 2, 2004.
- Hisaya Fujioka, Kyoto University, H_∞ *feedback design and command shaping for digital servo systems*, April 23, 2004.
- Fabio Celani, Norwegian University of Science and Technology, *Observers for Euler-Lagrange systems with position measurements*, May 7, 2004.
- Daizhan Cheng, Institute of Systems Science, CAS, China, *Control of switched systems*, May 14, 2004.
- Per Olov Lindberg, Linköping University, *New fast and accurate methods for convex multicommodity flow problems*, June 4, 2004.
- Yasushi Iwatani, Tokyo Institute of Technology, *Stability tests based on eigenvalue loci for piecewise linear systems*, June 11, 2004.

5 Publications

5.1 Papers in journals and books (published and accepted)

[A1] D. A. Anisi, J. Hamberg and X. Hu, *Nearly time-optimal paths for a ground vehicle*, Journal of Control Theory and Applications, Vol. 1 No. 1(2003), 2-8.

[A2] A. Blomqvist, A. Lindquist and R. Nagamune, *Matrix-valued Nevanlinna-Pick interpolation with complexity constraint: An optimization approach*, IEEE Transactions on Automatic Control 48(2003), 2172–2190.

[A3] G. Bortolin, S. Borg and P.-O. Gutman, *Modeling of the wet end of a paper mill with Dymola*, Mathematics and Computers in Simulation 65 (2004), 31-38.

[A4] C. I. Byrnes and A. Lindquist, *The uncertain generalized moment problem with complexity constraint*, New Trends in Nonlinear Dynamics and Control, W. Kang, M. Xiao and C. Borges (Eds.), New Trends in Nonlinear Dynamics and Control, Springer Verlag, 2003, 267–278.

[A5] C. I. Byrnes and A. Lindquist, *A convex optimization approach to generalized moment problems*, Control and Modeling of Complex Systems: Cybernetics in the 21st Century: Festschrift in Honor of Hidenori Kimura on the Occasion of his 60th Birthday, Koichi Hashimoto, Yasuaki Oishi, and Yutaka Yamamoto, Editors, Birkhäuser, 2003, 3–21.

[A6] C. I. Byrnes, T. T. Georgiou, A. Lindquist and A. Megretski, *Generalized interpolation in H-infinity with a complexity constraint*, Transactions of the American Mathematical Society, to be published.

[A7] D. Cheng, X. Hu and Y. Wang, *Non-regular feedback linearization of nonlinear systems via a normal form algorithm*, Automatica vol. 40, no. 3, March 2004.

[A8] H. Fujioka, *An LMI approach to multirate sampled-data* $\mathbf{H}_\infty$ *control synthesis*, Trans. on Society of Instrument and Control Engineers 40(2003).

[A9] T. T. Georgiou and A. Lindquist, *Kullback-Leibler approximation of spectral density functions*, IEEE Transactions on Information Theory 49(Dec. 2003), 2172–2190.

[A10] X. Hu and T. Ersson, *Active observers for nonlinear systems*, to appear in Automatica.

[A11] L. Iannelli, K. H. Johansson, U. Jönsson, and F. Vasca, *Dither for smoothing relay feedback systems*, *IEEE Transactions on Circuits and Systems-I: Fundamental Theory and Applications*, 50(8):1025–1035, August 2003.

[A12] I. Ioslovich, P.-O. Gutman, and I. Seginer, *Dominant parameter selection in the marginally identifiable case*, Mathematics and Computers in Simulation, 65(1-2), 127-136, April 2004.

[A13] I. Ioslovich and P.-O. Gutman, *On optimal smooth control determination*, Automatica, 2004 (accepted).

[A14] U. Jönsson, C. F. Martin, and Y. Zhou, *Trajectory planning for systems with a multiplicative stochastic uncertainty*, To appear in International Journal of Control, 2004.

[A15] U. Jönsson and A. Megretski, *Robustness of hyberbolic limit cycles*, To appear in V. Dayawansa, A. Lindquist, and Y. Zhou, editors, *New Directions in Control and Applications*, Lecture Notes in Control and Information Sciences. Springer-Verlag, 2004.

[A16] C.-Y. Kao, A. Megretski and U. Jönsson, *Specialized fast algorithms for IQC feasibility and optimization problems*, Automatica 40(2) 2004, 239-252.

[A17] C.-Y. Kao and B. Lincoln, *Simple stability criteria for systems with time-varying delays*, Automatica 40(8) 2004, 1429-1434.

[A18] B. M. Mirkin and P.-O. Gutman, *Decentralized output-feedback MRAC of linear state delay systems*, IEEE Transactions on Automatic Control 23(9),1613-1619,September 2003.

[A19] J. Pettersson and P.-O. Gutman, *Automatic tuning of the window size in the Box Car Back Slope data compression algorithm*, Journal of Process Control 14(4), 431-439, June 2004.

[A20] H. Rehbinder and X. Hu, *Drift-free attitude estimation for accelerated rigid bodies*, Automatica vol. 40, no. 4, April 2004.

[A21] H. Rehbinder and X. Hu, *Drift-free attitude estimation using quasi-linear observers*, to appear in New Directions and Applications in Control Theory, Springer-Verlag.

[A22] M. Stolpe and K. Svanberg, *A stress-constrained truss-topology and material-selection problem that can be solved by linear programming*, Structural and Multidisciplinary Optimization 27:1-2(2004), 126-129.

[A23] Y. Wang, D. Cheng and X. Hu, *Problems on time-varying port-controlled Hamiltonian systems: geometric structure and dissipative realization*, to appear in Automatica.

5.2 Papers in conference proceedings (published and accepted)

[C1] S. Almér, U. Jönsson, C. Kao and J. Mari, *Stability analysis of a class of PWM systems using sampled-data modeling*, In *Proceedings of the IEEE Conference on Decision and Control 2003*, pages 4794–4799, Maui, Hawaii, USA, 2003.

[C2] S. Almér, U. Jönsson, C. Kao and J. Mari, *Global stability analysis of DC-DC converters using sampled-data modeling*, In *Proceedings of the American Control Conference*, 2004.

[C3] S. Almér, U. Jönsson, C-Y Kao, and J. Mari, *Stability analysis of DC-DC converters*, In *Reglermöte 2004, Preprints*, 2004.

[C4] D. A. Anisi, J. Hamberg and X. Hu, *Nearly time-optimal paths for a ground vehicle*, Reglermötet 2004, Göteborg, Sweden, May 2004.

[C5] A. Blomqvist and G. Fanizza, *Identification of rational spectral densities using orthonormal basis functions*, Proceedings of Symposium on System Identification, 2003, Rotterdam, The Netherlands.

[C6] A. Blomqvist, G. Fanizza, and R. Nagamune, *Computation of bounded degree Nevanlinna-Pick interpolants by solving nonlinear equations*, Proc. 42nd IEEE Conf. on Decision and Control, Dec. 2003, 4511-4516, Maui, Hawaii.

[C7] A. Blomqvist and B. Wahlberg, *A data driven orthonormal parameterization of the generalized entropy maximization problem*, Proc. of 16th International Symposium on Mathematical Theory of Networks and Systems , Jul. 2004, Leuven, Belgium.

[C8] G. Bortolin, P.-O. Gutman and B. Nilsson , *Modeling of curl and twist in multi-ply paperboard*, Control Systems 2004, Quebec City, Canada.

[C9] D. Cheng and X. Hu, *Semi-global non-regular linearization of nonlinear systems*, to appear in Asian Control Conference 2004.

[C10] H. Fujioka, *Implementing systems with two point boundary conditions for a CACSD Package of sampled-data systems*, Proc. 2004 Amer. Contr. Conf. (2004), 5016-5021.

[C11] H. Fujioka, *Computing* $\mathbf{L}_2$*-gain of finite-horizon systems with boundary conditions*, Proc. 16th Int. Sym. MTNS (2004).

[C12] H. Fujioka, S. Hara, and Y. Yamamoto, *Sampled-Data Control Toolbox: Object-oriented software for sampled-data feedback control systems*, Proc. 2004 IEEE Conf. Computer Aided Control Systems Design (2004).

[C13] C. Gaillemard and A. Johansson, *Modeling of the moisture content of the paper in the drying section of a paper mill*, Control Systems(2004), 183-187.

[C14] T. T. Georgiou and A. Lindquist, *Kullback-Leibler approximation of spectral density functions*, 42nd IEEE Conference on decision and Control, Maui, Hawaii, Dec. 2003, 4237–4242.

[C15] T. Gustavi, X. Hu and L.-M. Johansson, *Path following and target tracking for mobile robots with limited sensor information*, Reglermöte 2004, Göteborg, may 2004.

[C16] X. Hu, D. Fuentes and T. Gustavi, *Sensor-based navigation coordination for mobile robots*, Proc. 42nd IEEE Conf. on Decision and Control, Dec. 2003.

[C17] L. Iannelli, K. H. Johansson, U. Jönsson, and F. Vasca, *Effects of dither shapes in nonsmooth feedback systems: Experimental results and theoretical insight*, In *Proceedings of the IEEE Conference on Decision and Control 2003*, pages 4284–4290, Maui, Hawaii, USA, 2003.

[C18] L. Iannelli, K. H. Johansson, U. Jönsson, and F. Vasca, *Practical stability and limit cycles of dithered relay feedback systems*, In *Proceedings of the European Control Conference*, Cambridge, UK, 2003.

[C19] L. Iannelli, K. H. Johansson, U. Jönsson, and F. Vasca, *Dither shape in the averaging of switched systems*, In *In the Proceedings of the American Control Conference*, 2004.

[C20] I. Ioslovich, P.-O. Gutman, and R. Linker, *Optimal greenhouse control*, Proc. 2003 XXX CIOSTA/CIGR V Conference on Management and technology applications to empower agriculture and agro-food systems, 22-24 September 2003, University of Torino, , Italy.

[C21] U. Jönsson and A. Megretski, *On the robustness of limit cycles*, In *16th International Symposium on Mathematical Theory of Networks and Systems (MTNS 2004)*, 2004.

[C22] C.-Y. Kao and A. Megretski, *A new barrier function for IQC optimization problems*, Proceedings of the 2003 American Control Conference, 5(2003), 4281-4286.

[C23] C.-Y. Kao and A. Rantzer, *Stability criteria for systems with bounded uncertain time-varying delay*, Proceedings of the 2003 European Control Conference.

[C24] C.-Y. Kao, A. Megretski, U. Jönsson, and A. Rantzer, *A matlab toolbox for robustness analysis*, In *IEEE Conference on Computer Aided Control Systems Design*, Taipei, Taiwan, 2004. To appear.

[C25] Y. Kuroiwa and H. Kimura, *H_∞ control with preview and delay*, In Proceedings of the American Control Conference, Boston, USA, 2004.

[C26] M. Mazo, A. Speranzon, K-H. Johansson and X. Hu, *Collaborative tracking of a moving object using directional sensors*, Proc. ICRA 2004, April 2004.

[C27] B. M. Mirkin and P.-O. Gutman, *Coordinated decentralized output-feedback MRAC: the case of MIMO subsystems with delayed communications*, 42nd IEEE Conference on Decision and Control, Hyatt Regency Maui, Hawaii, USA, December 9–12, 2003.

[C28] B. M. Mirkin and P.-O. Gutman, *State Feedback MRAC of State Delayed Systems with Actuator Failures*, 12th IEEE Mediterrenean Conference on Control and Automation MED'04, Kusadasi, Turkey, June 6–9, 2004.

[C29] B. M. Mirkin and P.-O. Gutman, *Adaptive Control of Linear Time Delay Systems*, American Control Conference, ACC-2004, Boston, USA, June 30–July 2, 2004.

5.3 Other publications

[O1] A Megretski, C. Kao, U. Jönsson and A. Rantzer, *A Guide To IQC-beta: Software for Robustness Analysis*, http://www.math.kth.se/~cykao/.

5.4 Technical reports and preprints

[R1] A. Bicchi, X. Hu, K-H Johansson, U. Jönsson, A. Martinelli, and A. Sampieri, *Algorithms for control abstraction of nonlinear systems*, Technical Report IST-2001-37170, RECSYS, 2003.

[R2] A. Blomqvist and R. Nagamune, *Optimization-based computation of analytic interpolants of bounded degree*, Submitted for publication.

[R3] A. Blomqvist and B. Wahlberg, *On affecting the model error distibution in AR estimation using pre-filtering*, Submitted for publication.

[R4] C. I. Byrnes and A Lindquist, *Interior point solutions of variational problems and global inverse function theorems*, submitted for publication.

[R5] F. Carlsson, A. Forsgren, H. Rehbinder and K. Eriksson, *Using eigenstructure of the Hessian to reduce the dimension of the intensity modulated radiation therapy optimization problem*, Report TRITA-MAT-2004-OS1, Department of Mathematics, Royal Institute of Technology, 2004.

[R6] S. Cedervall and X. Hu, *Active nonlinear observers for mobile systems*, Submitted to CDC 2004.

[R7] D. Cheng, X. Hu and C. Martin, *On the smallest enclosing balls*, Submitted to Discrete Applied Mathematics.

[R8] A. Forsgren and M. Prytz, *Telecommunications network design*, Manuscript in preparation for the forthcoming *Handbook of Optimization in Telecommunications*, P. M. Pardalos and M. G. C. Resende, eds., Kluwer Academic Publishers.

[R9] H. Fujioka, *Command shaping for sampled-data servo systems with constraints*, (in Japanese), Submitted for publication.

[R10] T. Gustavi, X. Hu and L.-M. Johansson, *Path following and target tracking for mobile robots with limited sensor information*, Submitted to CDC 2004.

[R11] T. Gustavi, X. Hu and L.-M. Johansson, *Path following and obstacle avoidance for mobile robots using a virtual vehicle approach*, Submitted to *IEEE Trans. Robotics*.

[R12] L. Iannelli, K.-H. Johansson, U. Jönsson, and F. Vasca, *Conditions on the dither shape in the averaging of switched systems*, Technical Report TRITA/MAT-03-OS08, Department of Mathematics, Royal Institute of Technology, 2003.

[R13] U. Jönsson, *Robustness of transitions in switched linear systems*, Submitted to International Journal of Robust and Nonlinear Control, 2003.

[R14] U. Jönsson and A. Megretski, *A small gain theory for limit cycles*, Technical Report TRITA/MAT-03-OS07, Department of Mathematics, Royal Institute of Technology, 2003, Conditionally accepted for publication in SIAM Journal of Control and Optimization.

[R15] R. Nagamune and A. Blomqvist, *Sensitivity shaping with degree constraint by nonlinear least-squares optimization*, Submitted for publication.

6 Awards

Anders Lindquist was awarded the *George S. Axelby Outstanding Paper Award* of the IEEE Control Systems Society (CSS) for the year 2003.

7 Presentations

[P1] S. Almér, *Stability analysis of DC-DC converters*, Reglermöte 2004, May 26-27 2004.

[P2] S. Almér, *Global Stability Analysis of DC-DC Converters Using Sampled-Data Modeling*, American Control Conference 2004, June 30 - July 02 2004.

[P3] A. Blomqvist, *Identification of Rational Spectral densities Using Orthonormal Basis Functions*, 13th IFAC Symposium on System Identification, Rotterdam, The Netherlands, August 28, 2003.

[P4] A. Blomqvist, *Identification of Rational Spectral densities Using Orthonormal Basis Functions*, Swedish-Ukrainian workshop on robust control, Crimea, Ukraine, September 6, 2003.

[P5] A. Blomqvist (joint with B. Wahlberg), *On ARMA estimation using Pre-Filetering*, The 11th ERNSI workshop, Noordwijkerhout, The Netherlands, October 3, 2003.

[P6] A. Forsgren, *Interior methods for optimization*, National University of Singapore, Singapore, July 4, 2003.

[P7] A. Forsgren, *On the solution of KKT systems that arise in optimization*, The 5th International Congress on Industrial and Applied Mathematics, Sydney, Australia, July 7–11, 2003.

[P8] A. Forsgren, *On the solution of linear equations arising in interior methods for nonconvex optimization*, The 18th International Symposium on Mathematical Programming, Copenhagen, Denmark, August 18–22, 2003.

[P9] A. Forsgren, *Interior methods for nonlinear optimization*, The GAMM 2004 Annual Meeting, Dresden, Germany, March 21–27, 2004.

[P10] H. Fujioka, *Implementing systems with two point boundary conditions for a CACSD Package of sampled-data systems*, 2004 Amer. Contr. Conf., June 30-July 2, 2004.

[P11] H. Fujioka, *Computing $\mathbf{L}_2$-gain of finite-horizon systems with boundary conditions*, 16th Int. Symp. MTNS, July 5-9, 2004.

[P12] T. Gustavi, *Sensor-based navigation coordination for mobile robots*, The 42nd IEEE Conference on Decision and Control, Maui, Hawaii, December 12, 2003.

[P13] T. Gustavi, *Path following and target tracking for mobile robots with limited sensor information*, Poster presentation, Reglermöte 2004, Göteborg, May 2004.

[P14] P.-O. Gutman, *On optimal smooth control determination*, Workshop on Dynamical Systems and Control. Center for Mathematical Sciences, Technion, Haifa. 20-22 June 2004.

[P15] X. Hu, *Nonlinear observers and active sensing*, First Swedish-Chinese Control Conference, Stockholm, August, 2003.

[P16] X. Hu, *A Virtual Vehicle Approach to Motion Control of Mobile Systems*, ICRA 2003 Workshop on New Developments in Mobile Robot Manipulation, Taipei, September, 2003 (Invited presentation).

[P17] X. Hu, *Path Following and Motion Control of Nonlinear Mobile Systems*, Robust control conference in Crimea, Ukraine, September, 2003.

[P18] X. Hu, *Algorithms for Control Abstraction of Nonlinear Systems*, First RECSYS Review Meeting, Padova, October, 2003.

[P19] X. Hu, *On Active Nonlinear Observers*, New Directions in Control Theory and Applications, Texas Tech university, November, 2003 (Invited presentation).

[P20] U. Jönsson, Local robustness of limit cycles, The First Swedish-Chinese Control Conference, KTH 2003.

[P21] U. Jönsson, A small gain theory for limit cycles, Robust control conference in Crimea, Ucraine, 2003.

[P22] U. Jönsson, A small gain theory for limit cycles, New directions and applications in control theory, Texas Tech university, 2003. (Invited presentation.).

[P23] U. Jönsson, On the robustness of limit cycles, International Symposium on Mathematical Theory of Networks and Systems (MTNS2004), Katholieke Universiteit Leuven, Belgium, 2004.

[P24] C.-Y. Kao, *Stability criteria for systems with bounded uncertain time-varying delays*, European Control Conference, Cambridge, UK, Septermber 3, 2003.

[P25] C.-Y. Kao, *Stability criteria for systems with bounded uncertain time-varying delays*, Robust Control Conference, Crimea, Ukraine, September 6, 2003.

[P26] C.-Y. Kao, *Analysis of systems with bounded uncertain time-varying delays*, Workshop on Control with Network Delays, Lund, Sweden, May 14, 2004.

[P27] Y. Kuroiwa, H_∞ *control with preview and delay*, American Control Conference, Boston, USA, June 30-July 02 2004.

[P28] A. Lindquist, *Generalized intepolation in* H^∞ *with applications to systems and control*, First Swedish-Chinese Control Conference, Stockholm, Sweden, August 21-22, 2003.

[P29] A. Lindquist, *An optimization approach to generalized moment problems with with complexity constraints*, Conference on Robust Control, Gurzuf, Crimea, Ukraine, 4-8 September 2003.

[P30] A. Lindquist, *Generalized Interpolation in* H^∞*: Solutions of Bounded Complexity*, New Directions and Applications in Control Theory, Texas Tech University. Lubbuck, Texas, November 14–15, 2003.

[P31] A. Lindquist, *Kullback-Leibler Approximation of Spectral Density Functions*, University of California, Berkeley, December 4, 2003.

[P32] A. Lindquist, *Kullback-Leibler Approximation of Spectral Density Functions*, 42nd IEEE Conference on decision and Control, Maui, Hawaii, Dec. 2003.

[P33] A. Lindquist, *An optimization approach to generalized moment problems with with complexity constraints*, Kyoto University, Japan, March 18, 2004.

[P34] A. Lindquist, *Generalized interpolation in* H^∞*: Solutions of bounded complexity*, International Workshop on Dynamical Systems and Control, Technion, Israel, June 20–22, 2004.

[P35] K. Svanberg, *Topology optimization of load-carrying structures*, Uppsala University, November 12, 2003.

8 Other activities

Stefan Almér

- Reviewed 1 paper for the 2003 Conference of Decision and Control and 1 paper for the 2004 American Control Conference.

Anders Blomqvist

- Visited Department for Econometrics, Operations Research and Systems Theory, Technische Universität Wien, Austria, January 12 - February 12, 2003.
- Referee for Automatica and Computational Statistics and Data Analysis.

Gianantonio Bortolin

- Participation in ERNSI Workshop, 6 - 8 October 2003 in Noordwijkerhout, The Netherlands.
- Participation in Control Systems 2004, 14-17 June 2004 in Quebec City, Canada.

Ulf Brännlund

- Responsible for the line of competence (kompetensinriktning), Systems eng ineering, for the schools of mechanical and vehicle engineering.
- Part time employed by Optimization Partner Stockholm AB.

Vanna Fanizza

- Participated in ERNSI meeting, October 6–8 2003, Noordwijkerhout, The Netherlands.
- Participated in IEEE Conference on Decision and Control in Maui, USA, December 2003.

Anders Forsgren

- Program Director, SIAM Aactivity Group on Optimization, 2001–2003.
- Associate editor for Mathematical Programming, Series A.
- Member of editorial board for Computational Optimization and Applications.
- Visited the University of California, San Diego, California, USA, January 11–17, 2004.
- Co-chair of the *8th SIAM Conference on Optimization*, to be held in Stockholm, May 15-19, 2005.
- Referee for Optimization in Engineering and BIT.

Hisaya Fujioka

- Referee for IEEE Transaction of Automatic Control, Automatica, European Journal of Control, International Journal of Systems Science, Asian Journal of Control, IEEE Conference on Decision and Control, IEEE Conference on Control Applications, IFAC Symp. on Large Scale Systems.
- Developed the minicourse on sampled-data control theory, 2004.

Christelle Gaillemard

- Participated in Reglermöte Göteborg, May 25-27 2004.

Ulf Jönsson

- Associate editor for IEEE Transactions on Automatic Control.
- Referee for IEEE Transactions on Automatic Control, IEEE Transactions Circuits and Systems, American Control Conference (2004), IEEE Conference on Decision and Control 2004.
- Participated in the conferences: European Control Conference, Cambridge, UK, 2003, IEEE Conference on Decision and Control, Maui, Hawaii, December 2003, American Control Conference, Boston, 2004, Reglermöte 2004 in Göteborg.

- One of three lecturers in Analysis of Feedback Systems : Theory and Computation in Graduate School in Systems and Control 2004, Belgium. Joint with R. Sepulchre and J. C. Willems.
- Developed the new graduate course 5B5766 Robust Control Theory, 2003. Jointly with C.-Y. Kao.

Chung-Yao Kao

- Referee for IEEE Transaction of Automatic Control, Automatica, IEEE Conference on Decision and Control.

Johan Karlsson

- Participated in First Swedish-Chinese Control Conference, Stockholm, Sweden, August 21-22, 2003.
- Participated in ERNSI Workshop System Identification 2003, Noordwijkerhout, The Netherlands, October 6-8 2003.
- Research visit at University of Minnesota, USA, April 30 - June 18 2004.
- Participated in Fourth European Congress of Mathematics, Stockholm, Sweden, June 27 - July 2, 2004.

Yohei Kuroiwa

- Participation in ERNSI Workshop, Noordwijkerhout, The Netherlands, October 6-8 2003.
- Participation in Reglermöte, Göteborg, May 25-27 2004.

Anders Lindquist

- Chairman, Department of Mathematics, Royal Institute of Technology.
- Member Central Faculty Board ("Centrala fakultetsnämnden"), KTH.
- Vice-chairman, Division VII of the Royal Swedish Academy of Engineering Sciences (IVA).
- Board Member, Strategic Center for Autonomous Systems, KTH.
- Scientific leader, Mittag-Leffler Institut, Spring 2003.
- Affiliate Professor, Washington University, St Louis, USA.
- Advisory Board of the Institute for Mathematics of the Life Sciences, Texas Tech University, Texas, USA.
- Member, Board of Governors of the Israel Institute of Technology (Technion) in Haifa.
- Member of the Board of the Foundation "Nordic Information Processing" (BIT).
- Team Leader, European Research Network for System Identification (ERNSI), TMR network.
- Team leader, European project RECSYS.
- Member, 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.
- Examiner (Revisore), University of Padova, Italy.
- Member, Steering Committee of the ERCIM Working Group on Control and System Theory.
- Member, Organizing Committee of Fourth European Mathematical Congress, Stockholm, June 27–July 2, 2004.
- Member, Steering Committee of MTNS2004, Catholic Univerity of Leuven, Belgium on July 5-9, 2004.

Krister Svanberg

- Referee for Int J Numerical Methods in Engineering (3 papers).
- Referee for Int J Solids and Structures.
- Referee for Structural and Multidisciplinary Optimization.
- In the evaluation committee at the doctoral dissertation of Martin Carlsson, Aeronautical and Vehicle Engineering, KTH, May 28, 2004.