FIRST SWEDISH-ISRAELI CONTROL CONFERENCE

The first Swedish-Israeli Control Conference will be held September 27-28, 2004 at KTH, the Royal Institute of Technology, Stockholm, Sweden. This is a workshop in systems and control, the purpose of which is to promote exchange between the Swedish and the Israeli control communities.

The workshop is organized by the Division of Optimization and Systems Theory, Department of Mathematics of the Royal Institute of Technology, under the auspices of the Israel Association for Automatic Control, the Swedish Technion Society and Israeli Ministry of Foreign Affairs. The chairman of the workshop is Professor Anders Lindquist (alq@math.kth.se). The Israeli contact person of the workshop is Prof. Per-Olof Gutman (peo@tx.technion.ac.il).

The workshop will start with a reception in the evening of September 26. A banquet will be held in the evening of 27 September.

List of speakers:

Itzhack Y. Bar-Itzhack, Technion, Israel
Harry Dym, Weizmann Institute, Israel
Paul A. Fuhrmann, Ben-Gurion University, Israel
Alexander Ioffe, Technion, Israel
Ilya Ioslovich, Technion, Israel
Arie Leizarowitz, Technion, Israel
David Levanony, Ben-Gurion University, Israel
Itzchak Lewkowicz, Ben-Gurion University, Israel
Leonid Mirkin, Technion, Israel
Yaakov Oshman, Technion, Israel
Zalman J. Palmor, Technion, Israel
Uri Shaked, Tel Aviv University, Israel

Damir Z. Arov, Åbo Akademi, Finland
Andrej Ghulchak, Lund University, Sweden
Torkel Glad, Linköping University, Sweden
Håkan Hjalmarsson, Royal Institute of Technology, Sweden
Xiaoming Hu, Royal Institute of Technology, Sweden
Karl-Henrik Johansson, Royal Institute of Technology, Sweden
Rolf Johansson, Lund University, Sweden
Ulf Jönsson, Royal Institute of Technology, Sweden
Anders Lindquist, Royal Institute of Technology, Sweden
Anton Shiriaev, Umea University, Sweden
Jonas Sjöberg, Chalmers University of Technology, Sweden
Olof Staffans, Åbo Akademi, Finland

A list of titles and abstracts is printed below. The program is found on this web site.

The workshop is open to all interested. Non-speakers need to register and pay the registration fee (SEK 1500) to Ms. Erika Appel, appel@math.kth.se Tel. +46 8 7906755. All meals, the reception, and dinner are included in the registration fee. Vegetarian food will also be available.

List of titles (as arrived by 2004-09-17)

Itzhack Y. Bar-Itzhack, Technion, Israel

Pseudo-Linear Kalman-Filter and its Application to Spacecraft Rate and Attitude Determination

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Harry Dym, Weizmann Institute, Israel

An augmented basic interpolation problem

Paul A. Fuhrmann, Ben Gurion University, Israel

BEHAVIOR HOMOMORPHISM AND SYSTEM EQUIVALENCE

Alexander Ioffe, Technion, Israel

Nonsmooth analysis and optimal control

Ilya Ioslovich, Technion, Israel

SEASONAL OPTIMAL CONTROL POLICY FOR GROWTH OF GREENHOUSE LETTUCE WHILE AVOIDING HEALTH HAZARDS

Arie Leizarowitz, Technion, Israel

Average-cost optimality for multichain MDPs, and overtaking optimality for unicost MDPs

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David Levanony, Ben-Gurion University, Israel

On the consistent filtering of convergent semimartingales

Itzchak Lewkowicz, Ben-Gurion University, Israel

Matrix sign function and the Nevanlinna-Pick Interpolation

Leonid Mirkin, Technion, Israel

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Robust H_1 Output-Feedback Control

Damir Z. Arov, Abo Akademi, Finland

Generalized solutions of the Kalman-Yakubovich-Popov inequality for continuous-time systems.

Andrej Ghulchak, Lund University, Sweden

Robust Stabilizability and Unstable Zero-Pole Cancellations - Analysis and Synthesis

Torkel Glad, Linköping University, Sweden

Step responses of nonlinear non-minimum phase systems

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Quantification of the Variance Error in Estimated Frequency Functions

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Active Nonlinear State Observers

Karl H. Johansson, Royal Institute of Technology, Sweden

Multi-robot coordination under limited communication

Rolf Johansson, Lund University, Sweden

OBSERVER-BASED STRICT POSITIVE REAL (SPR) SYSTEMS

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On the Robustness of Oscillator Networks

Anders Lindquist, Royal Institute of Technology, Sweden

Kullback-Leibler approximation of spectral densities

Anton Shiriaev, Umeå University, Sweden

Generating and Controlling Stable Walking Patterns in Bipeds

Jonas Sjöberg, Chalmers University of Technology, Sweden

Estimating independent parameterized plant and noise models in nonlinear processes: possibilities of using linear model-on-demand in combination with instrumental variable techniques

Olof Staffans, Åbo Akademi, Finland

Passive and Conservative Infinite-Dimensional Linear State/Signal Systems

List of titles and abstracts (as arrived by 2004-09-17)

Itzhack Y. Bar-Itzhack, Technion, Israel

Pseudo-Linear Kalman-Filter and its Application to Spacecraft Rate and Attitude Determination

We consider the discrete dynamic system

$$\mathbf{x}_{k+1} = \mathbf{f}_k(\mathbf{x}_k, \mathbf{u}_k) + \mathbf{w}_k \tag{1.a}$$

where $\mathbf{x}_k \in \mathbb{R}^n$ is the state vector of the system at time t_k, $\mathbf{f}_k \in \mathbb{R}^n$ is the dynamics vector, $\mathbf{u}_k \in \mathbb{R}^p$ is a deterministic input vector at that time, and $\mathbf{w}_k \in \mathbb{R}^n$ is a vector of zero-mean white process-noise sequence. Also given is the measurement equation

$$\mathbf{y}_{k+1} = \mathbf{c}_k(\mathbf{x}_k, \mathbf{u}_k) + \mathbf{v}_k \tag{1.b}$$

where $\mathbf{y}_{k+1} \in \mathbb{R}^m$ is the measured vector, $\mathbf{c}_k \in \mathbb{R}^m$ is the measurement function and $\mathbf{v}_{k+1} \in \mathbb{R}^m$ is vector of zero-mean white measurement-noise sequence. $E\left\{\mathbf{w}_k \mathbf{w}_j^T\right\} = Q_k \delta_{k,j}$ where $\delta_{k,j}$ is the kronecker delta and $E\left\{\mathbf{v}_k \mathbf{v}_j^T\right\} = R_k \delta_{k,j}$ $E\left\{\mathbf{w}_k \mathbf{v}_j^T\right\} = 0 \quad \forall$ k, j $\hat{\mathbf{x}}_0 = E\left\{\mathbf{x}_0\right\}$. Eqs. (1) can be written as:

$$\mathbf{x}_{k+1} = F_k(\mathbf{x}_k, \mathbf{u}_k)\mathbf{x}_k + B_k(\mathbf{x}_k, \mathbf{u}_k) + \mathbf{w}_k \tag{2.b}$$
$$\mathbf{y}_{k+1} = C_k(\mathbf{x}_k, \mathbf{u}_k)\mathbf{x}_k + \mathbf{v}_k \tag{2.c}$$

where $F_k \in \mathbb{R}^{n\times n}$, $B_k \in \mathbb{R}^{n\times p}$ and $C_k \in \mathbb{R}^{m\times n}$. Then it is possible to apply the linear Kalman filter (KF) algorithm to this system in order to compute $\hat{\mathbf{x}}_k$, the estimate of $\mathbf{x}_k$. When applying the algorithm we evaluate the matrices $F_k(\mathbf{x}_k, \mathbf{u}_k)$, $B_k(\mathbf{x}_k, \mathbf{u}_k)$ and $C_k(\mathbf{x}_k, \mathbf{u}_k)$ using the known deterministic forcing function $\mathbf{u}_k$ and the current best estimate of $\mathbf{x}_k$.

Such case arises in the problem of estimating the rate and attitude of gyro-less spacecraft (SC). The measurements are usually unit vectors or quaternions. In order to obtain a good estimate of the angular velocity vector, $\boldsymbol{\omega}_k$, we use Euler's equation:

$$\dot{\boldsymbol{\omega}} = I^{-1}[(I\boldsymbol{\omega} + \mathbf{h})\times]\boldsymbol{\omega} + I^{-1}(\mathbf{T} - \dot{\mathbf{h}}) \tag{3.a}$$

where I is the SC inertia matrix, $\mathbf{h}$ is the angular momentum of the momentum wheels, and $\mathbf{T}$ is the external torque acting on the SC. Together with this equation we use the following quaternion differential equation:

$$\dot{\mathbf{q}} = \tfrac{1}{2} Q \boldsymbol{\omega} \tag{3.b}$$

where

$$Q = \begin{bmatrix} q_4 & -q_3 & q_2 \\ q_3 & q_4 & -q_1 \\ -q_2 & q_1 & q_4 \\ -q_1 & -q_2 & -q_3 \end{bmatrix} \tag{3.c}$$

We augment the nonlinear equations Eqs. (3.a) and (3.b) to form the following dynamics equation, which includes the noise terms, $\mathbf{w}$:

$$\begin{bmatrix} \dot{\boldsymbol{\omega}} \\ \dot{\mathbf{q}} \end{bmatrix} = \begin{bmatrix} I^{-1}[(I\boldsymbol{\omega}+\mathbf{h})\times] & 0 \\ \tfrac{1}{2}Q & 0 \end{bmatrix} \begin{bmatrix} \boldsymbol{\omega} \\ \mathbf{q} \end{bmatrix} + \begin{bmatrix} I^{-1}(\mathbf{T} - \dot{\mathbf{h}}) \\ \mathbf{0} \end{bmatrix} + \begin{bmatrix} \mathbf{w}_{\omega} \\ \mathbf{w}_{q} \end{bmatrix} \tag{4.a}$$

The zero-mean white-noise vector $\mathbf{w}_{\omega}$ accounts for the inaccuracies in the modeling of the SC angular dynamics, and is $\mathbf{w}_{q}$ a zero-mean white-noise vector that accounts for modeling errors in the quaternion dynamics. Obviously, after quantization, Eq. (4.a) is in the form of Eq. (2.b).

When the vector $\mathbf{b}_{m,k}$ is measured, the filter measurement equation is nonlinear but it can be put in the form:

$$\mathbf{b}_{m,k} = C_k(\mathbf{r}_k, \mathbf{q}_k)\mathbf{q}_k + \mathbf{v}_{b,k} \tag{4.b}$$

where $\mathbf{v}_{b,k}$ is a zero mean white sequence measurement noise,

$$C_k(\mathbf{r}_k, \mathbf{q}_k) = Q_k^T \Theta_k \tag{5.a}$$

Q_k is according to Eq. (3.c),

$$\Theta_k = \begin{bmatrix} [\mathbf{r}_k \times] & \mathbf{r}_k \\ -\mathbf{r}_k^T & 0 \end{bmatrix} \tag{5.b}$$

and $[\mathbf{r}_k \times]$ is the cross-product matrix defined as:

$$[\mathbf{r}_k \times] = \begin{bmatrix} 0 & -r_z & r_y \\ r_z & 0 & -r_x \\ -r_y & r_x & 0 \end{bmatrix}_k \tag{5.c}$$

When the quaternion $\mathbf{q}_{m,k}$ is measured, the measurement equation is simply the following linear equation:

$$\mathbf{q}_{m,k} = \begin{bmatrix} 0 & I_4 \end{bmatrix} \mathbf{q}_k + \mathbf{v}_{q,k} \tag{6}$$

where I_4 is the 4th dimensional identity matrix and $\mathbf{v}_{qk}$ is a zero-mean white sequence measurement noise,

We ran numerous cases with simulated and real data. For reasonable initial estimation errors, the pseudo-linear filter converged. Like in the case of the extended KF, no convergence proofs are known to exist but empirically, at least for the problem on hand, this approach yielded very good results.

Harry Dym, Weizmann Institute, Israel

An augmented basic interpolation problem

A number of bitangential interpolation problems in the Schur class $\mathcal{S}^{p\times q}(\mathbb{D})$ of $p \times q$ mvf's (matrix valued functions) that are holomorphic and contractive in the open unit disc $\mathbb{D} = \{\lambda \in \mathbb{C} : |\lambda| < 1\}$ can be incorporated into a general scheme that is formulated in terms of an observable pair $\{C \in \mathbb{C}^{m\times n}, A \in \mathbb{C}^{n\times n}\}$, and a positive semidefinite solution P of the Stein equation

$$P - A^*PA = C^*JC, \quad \text{where} \quad J = \begin{bmatrix} I_p & 0 \\ 0 & -I_q \end{bmatrix} \quad \text{and} \quad p + q = m.$$

In this setting, the aim is to describe the set $\widehat{\mathcal{S}}(C, A, P)$ of mvf's $S \in \mathcal{S}^{p\times q}(\mathbb{D})$ that meet the following three conditions, wherein $F(\lambda) = C(I_n - \lambda A)^{-1}$.

(C1) $[I_p \quad -S]Fu$ belongs to the Hardy space H_2^p for every $u \in \mathbb{C}^n$.

(C2) $[-S^* \quad I_q]Fu$ belongs to the Hardy space $H_2^{q\perp}$ for every $u \in \mathbb{C}^n$.

(C3) $\displaystyle\frac{1}{2\pi}\int_0^{2\pi} F(e^{i\theta})^* \begin{bmatrix} I_p & -S(e^{i\theta}) \\ -S(e^{i\theta})^* & I_q \end{bmatrix} F(e^{i\theta})d\theta \le P.$

The complexity of the problem depends upon the spectrum $\sigma(A)$ of A and whether or not P is invertible.

In this talk I will adapt the methodology of Katsnelson, Kheifets and Yuditskii (which is based on the feedback coupling formula of Arov and Grossman for the unitary extensions of a given isometric operator) to obtain a description of the set $\widehat{\mathcal{S}}(C, A, P)$ that is applicable to both singular and nonsingular P without any constraints on $\sigma(A)$.

Paul A. Fuhrmann, Ben Gurion University, Israel

BEHAVIOR HOMOMORPHISM AND SYSTEM EQUIVALENCE

The aim of this talk is to introduce the concept of behavior homomorphism and to present one of its principal application to behavioral theory and that is the unified derivation of equivalence results for different behavior representations. The question of equivalence is to characterize, within a class of representations, when two system representations give rise to the same behavior. These problems are not new. The Kalman state space isomorphism is of this type. So is Rosenbrock's notion of strict system equivalence and its modification known as Fuhrmann system equivalence.

Our approach leads to a unified theory of system equivalence.

Alexander Ioffe, Technion, Israel

Nonsmooth analysis and optimal control

The basic dynamic optimization model to be discussed in the talk will be a Mayer-type optimal control problem with state constraints for systems governed by ordinary differential inclusions. The latter determines the need in nonsmooth analysis for adequate handling of the problem. We shall basically discuss the development and state-of-art of the theory of necessary optimality conditions for problems of this type and implications for other types of optimal control problems. The analogy with the classical calculus of variations will be especially emphasized.

Ilya Ioslovich, Technion, Israel

Seasonal Optimal Control Policy for Growth of Greenhouse Lettuce while Avoiding Health Hazards

Lettuce with high nitrate levels is unmarketable in the European Union because of the possible health hazards. Corresponding standard limits for nitrate concentration are inposed separately on summer and winter crops. Predicting nitrate level at harvest from the environmental history of the crop is now possible, based on a recently developed dynamic growth model. In an attempt to optimize the growing process, this model is now extended by adding a simple greenhouse module, where temperature and nitrate supply rate can be controlled. Two cases are considered: (1) fixed spacing, as in traditional soil-grown crops, and (2) potted or floating plants, where continuously variable spacing can be used as a third control variable. The optimization criterion is formulated for a market-quota situation, and the analysis

based on the optimal control theory is used to explore the structure of the optimal policy. Two simplifying assumptions are made, (1) that the weather is constant throughout the growing period and (2) that photosynthesis and growth are not inhibited due to extreme levels of the carbohydrate pool in the plants.
The results show that the optimal policy for the variable spacing case is independent of the age of the crop. The canopy density (leaf area index) is maintained constant by continuously increasing the spacing, and the optimal temperature trajectory alternates, loosely speaking, between the maximum and minimum permissible levels. If, under the prevailing light level, the minimum temperature cannot ensure a sufficiently low crop nitrate level, the supply rate of nitrate must be reduced.
The optimal control policy for the fixed spacing case is to start with the highest permissible temperature and with abundant nitrate supply. At certain points in time, a switch down to the temperature of unventilated and unheated greenhouse, and later to the lowest permissible temperature, may be required. Finally, a switch to the lowest permissible nitrate supply rate may also be needed.
The variable-spacing case is analyzed first. Next, the fixed-spacing case is explored. An algorithmic solution method is outlined for each of the cases and sample results are compared.

This is joint work with Ido Seginer and Per-Olof Gutman.

Arie Leizarowitz, Technion, Israel

Average-cost optimality for multichain MDPs, and overtaking optimality for unicost MDPs

Markov Decision Processes (MDPs) are used to model various stochastic dynamical systems arising in engineering and economics. We consider discrete-time, infinite horizon MDPs with finite state space and compact action sets, employing the long-run average cost criterion. In the unichain situation the *single optimality equation* is sufficient to study and characterize optimal policies. In the first part of my talk I'll focus on *multichain* MDPs, for which it is well-known that the *pair of optimality equations* is required. I'll show, however, that one can identify certain subsets of the state space, such that restricting the study of the single optimality equation to these subsets yields optimal policies for the multichain MDP under consideration.

In the second part of the talk I'll describe the *overtaking optimality* notion, which is stronger than the long-run average cost criterion. In general, overtaking optimal policies do not exist even in situations where average-cost optimal policies are guaranteed. I'll show, however, that when restricting to the class of unicost MDPs (a class which includes, in particular, all the unichain MDPs), then overtaking optimal policies exist generically, in a certain natural metric.

David Levanony, Ben-Gurion University, Israel

On the consistent filtering of convergent semimartingales

The estimation of a class of continuous, convergent semimartingales, observed via a linear noisy sensor, is considered. In particular, conditions ensuring the consistency of the Bayesian estimator are established. These are in the form of a Persistence of Excitation (PE) property. This PE condition is stronger than the one required in the case of the estimation of a constant random vector. It coincides with the latter, when the unobserved semimartingale has a finite quadratic variation. An application of these results in a stochastic linear quadratic adaptive control problem will be discussed.

Itzchak Lewkowicz, Ben-Gurion University, Israel

Matrix sign function and the Nevanlinna-Pick Interpolation

Abstract: Let A be a matrix whose spectrum avoids the imaginary axis. It is well known that at least from the computational point of view, there is an interest in obtaining $\mathrm{Sign}(A)$. For example, if one wishes to solve the algebraic Lyapunov or Riccati equations, A has a certain Hamiltonian structure. The Matrix Sign Function Algorithm (MSFA) is the better known way to compute $\mathrm{Sign}(A)$: For $j = 0, 1, \ldots$ set $f_o(s) = s$ and $f_{j+1}(s) := \alpha_j f_j(s) + \frac{1-\alpha_j}{f_j(s)}$ with $\alpha_j \in (0, 1)$. Thus $f_j(A) \underset{j\to\infty}{\longrightarrow} \mathrm{Sign}(A)$, for any choice of of the sequence α_j .

One can view the MSFA as aimed at simultaneously mapping (in $\mathbb{C}$) a (possibly large) neighborhood of each eigenvalue of A, λ_k, to a vicinity of $\mathrm{Sign}(\lambda_k)$. Namely, a variant of an interpolation problem. This suggests the enlargement of the class of the mapping functions from the above $f_j(s)$, trying to gain the following advantages: (i) to facilitate incorporation of partial data on the spectrum of A, (ii) to reduce the degree of the mapping function and (iii) due to a known parameterization, a reduction in both the computational effort and the error caused by the large number of “nested” inverses involved in the MFSA.

It appears that a better choice for the set of function $f(s)$ is the class of all real rational functions which map each open (left and right) half plane onto itself (Foster) and in addition $f(s) = f(s^{-1})$.

Leonid Mirkin, Technion, Israel

On the delay margin of dead-time compensators

Dead-time compensators (DTC) are frequently regarded as being excessively sensitive to uncertainty in the loop delay. This claim, however, is based mostly

on empirical studies rather than on a rigorous analysis. In particular, despite a vast literature on the *calculation* of delay margins, there appear to be no studies of the *underlying reasons* of such a sensitivity. In this talk the latter issue will be addressed. By applying Nyquist criterion arguments, we show that the delay margin of DTC-based approaches decreases dramatically as the controller enforces the multiplication of the crossover frequencies in the control loop. Some design guidelines to avoid this phenomenon will be discussed.

This is joint work with Roman Gudin.

Yaakov Oshman, Technion, Israel

A New Estimation Error Lower Bound for Interruption Indicators in Systems with Uncertain Measurements

Optimal mean square error estimators of systems with interrupted measurements are infinite dimensional, because these systems belong to the class of hybrid systems. This renders the calculation of a lower bound for the estimation error of the interruption process in these systems of particular interest. In a recent attempt, presented at CDC'03, to calculate a Cram\'er-Rao-type lower bound for the state and interruption parameters of such systems, it has been shown that, whereas a nontrivial lower bound can be derived for the state variables, the resulting companion lower bound on the interruption process estimation error is trivially zero. In the present work a nonzero lower bound for a class of systems with Markovian interruption variables is proposed. Derivable using the well-known Weiss-Weinstein bound, this lower bound can be easily evaluated using a simple recursive algorithm. The proposed lower bound is shown to depend on a measure of the interruption chain transitional determinism, the measurement noise sensitivity to interruption process switchings, and a measure of the system's state estimability. In some cases, identified in this work, the proposed bound is tight. The use of the lower bound is illustrated via a simple numerical example.

This is joint work with Ilia Rapoport.

Zalman J. Palmor, Technion, Israel

A New Automatic Identifier and Tuner for Decentralized Dead Time Compensators

Interacting multivariable systems with multiple delays are quite common in the chemical and process industries as well as in communications networks. Satisfactory control of such systems, however, is known to be difficult to achieve. Decentralized classical controllers are typically employed under such circumstances, but the number of tuning methods for these simple controllers is extremely limited, even when process models are available.

In the SISO case DTCs are known to have the potential of improving control of systems with delays but require more involved tuning. No simple methods for their tunings exist. The situation in the MIMO case is much more difficult.

In this talk, I will present a novel algorithm that identifies the process in closed-loop and tunes the decentralized DTCs, yet is simple enough for industrial applications. Identification and tuning are automatic. The auto-identifier employs a decentralized relay sequentially, and input-output samples from one cycle that are developed in each loop are applied via FFT to identify the frequency response of the overall closed-loop. Least-squares frequency fitting is then employed to obtain the plant's transfer matrix. The tuning is done via a novel method based on characteristic loci under the requirement that robustness must be similar to that of a well-tuned DTC for the same process with no interactions.

For purposes of testing the autotuner, the well-known Swedish quadruple tank process was constructed and modified to introduce any multiple delays in the process.

In the talk, I will describe the basic principles of the algorithm and present experimental results demonstrating the efficiency of the autotuner relative to conventional controllers. If time allows I will also present some interesting results on the zeroes of the quadruple tank process with delays.

This work was supported by Israel Electric Company Ltd. and was carried out with the cooperation of the following graduate students: U. Burshtein, N. Albersheim and D. Sniederman.

Uri Shaked, Tel Aviv University, Israel

Robust H_1 Output-Feedback Control

A simple method for solving the problem of designing H1 -optimal output-feedback controllers for linear time-invariant systems with polytopic-type parameter uncertainty is presented. This problem was considered to be NP-hard due to the nonconvexity of the conditions that have been obtained for its solution. A simple transformation is suggested which makes the problem one of robust state-feedback control. The solution to the latter, which is expressed by LMIs that are convex in the decision variables, yields robust designs in cases where a mini-mization of the H1 -norm of the sensitivity or the complementary sensitivity transfer function matrices or the mixture of the two is sought. The proposed method can be used also in cases with time-delay in the inputs or the outputs. This time-delay turns out to be a delay in the resulting state equations to which our recent, descriptor based, design method is applied.

Various t design problems, which are taken from the literature, are solved by the new method. These include the distillation columns problem, with and without delay, (Morari et. al. AC 89), the MIMO design problem in Yaniv’s QFT book, and the latest

SRM design problem (Scherer et. al Automatica 2004). All the controllers obtained show a significant improvement compared to the results that were suggested in the past.

This is joint work with V. Suplin.

Damir Z. Arov, Abo Akademi, Finland

Generalized solutions of the Kalman-Yakubovich-Popov inequality for continuous-time systems.

We obtain necessary and sufficient contitions on the transfer function of a minimal well-posed continuous-time system in order for the system to have the following property: The Kalman-Yakubovich-Popov inequality for this system with scattering or impedance supply rate has at least one positive self-adjoint solution. This solution may be unbounded, and it may have an unbounded inverse. Among all the solutions of this inequality that satisfy an extra natural condition there is a minimal one and a maximal one. We also give an exact description of the cases where the given system is stable, or *-stable, or bi-stable in the strong sense with respect to at least one of the solutions of the KYP-inequality. The corresponding discrete-time scattering results were recently obtained by Arov, Kaashoek and Pick.

This is joint work with Olof Staffans.

Andrej Ghulchak, Lund University, Sweden

Robust Stabilizability and Unstable Zero-Pole Cancellations - Analysis and Synthesis

ABSTRACT: The classical criterion relays stabilizability of a plant to the absence of unstable zero-pole cancellations in the transfer function. For uncertain plants, that is if the numerator and denominator depend on a parameter, the situation is much more difficult - the robust stabilizability is no longer equivalent to the absence of unstable zero-pole cancellations for all parameter values in an uncertainty set. However, in case the numerator and the denominator depend affine on the uncertain parameter, a similar criterion can be derived but the constant uncertain parameters should be replaced by functions that take values in the uncertainty set. The criterion confirms robust stabilizability if "for all such functions the number of common unstable zeros in the resulting numerator and denominator does not exceed the total number of their unstable poles".

In this talk the problem of robust stability is first stated as (quasi)convex optimization, and the convex duality is used to obtain the dual problem. The problem can be viewed as a convex game between the controller (solution to the primal problem) and the uncertainty (solution to the dual one). The further analysis of the dual problem leads to the robust stabilizability criterion. The solution to the dual problem is used directly in controller synthesis. Several instructive examples are considered in details to illustrate the principle, among them the H-infinity optimization as a particular case. The principle has certain connections to the corona theorem and QFT method.

Torkel Glad, Linköping University, Sweden

Step responses of nonlinear non-minimum phase systems

For nonlinear systems, instability of the zero dynamics is known to correspond to the non-minimum phase property of linear systems. For linear systems it is also known that non-minimum phase is associated with certain step response behavior e.g. undershoot. It is shown that undershoot in nonlinear step responses occurs when the zero dynamics has an unstable manifold of odd dimension.

Håkan Hjalmarsson, Royal Institute of Technology, Sweden

Quantification of the Variance Error in Estimated Frequency Functions

In this talk we give an overview of results pertaining to the characterization of the variance error in estimated frequency functions. The focus is on recent expressions that, contrary to pre-existing results, are valid for finite model orders. The implication of these expressions for prefiltering, closed loop identification, model validation and input design are discussed. We also give a flavor of the underlying mathematical tools. ___

Xiaoming Hu, Royal Institute of Technology, Sweden

Active Nonlinear State Observers

In this talk we will discuss state observers for some classes of nonlinear mobile systems. For such systems, the observability does not only depend on the initial conditions, but also on the exciting control used. Thus, design of active control is an integral part in the design for state observers, which is in sharp contrast to the linear case. Here some sufficient conditions will be given for the existence and convergence of such an observer.

Karl H. Johansson, Royal Institute of Technology, Sweden

Multi-robot coordination under limited communication

In many networked control systems it is desirable to minimize the amount of information being communicated between controller nodes in order to avoid network congestion. In this talk we will discuss the interaction between control performance and communication policy for a particular multi-robot system, namely, a rendezvous problem for a team of autonomous vehicles communicating over quantized channels. The presented results illustrate how communication topologies based on various quantization schemes influence the control performance.

This is joint work with Fabio Fagnani, Alberto Speranzon and Sandro Zampieri.

Rolf Johansson, Lund University, Sweden

OBSERVER-BASED STRICT POSITIVE REAL (SPR) SYSTEMS

This lecture presents theory for stability analysis and design for a class of observer-based feedback control systems. Relaxation of the controllability and observability conditions imosed in the Yakubovich-Kalman-Popov (YKP) lemma can be made for a class of nonlinear systems described by a linear time-invariant system (LTI) with a feedback-connected cone-bounded nonlinear element. It is shown how a circle-criterion approach can be used to design an observer-based state feedback control which yields a closed-loop system with specified robustness characteristics. The approach is relevant for design with preservation of stability when a cone-bounded nonlinearity is introduced in the feedback loop. Important applications are to be found in nonlinear control with high robustness requirements.

Ulf Jönsson, Royal Institute of Technology, Sweden

On the Robustness of Oscillator Networks

Conditions for robust stability of networks of identical coupled oscillators are derived. We assume that the coupling of the network is such that the limit cycle of a single oscillator is embedded in the network solution. When this is the case the network is said to be synchronized and all oscillators remain in their nominal limit cycle. We provide conditions for the system to remain synchronized when the oscillators are perturbed and no longer identical. For a special case we discuss how the network topology can be designed for a specified rate of convergence to the synchronized state.

Anders Lindquist, Royal Institute of Technology, Sweden

Kullback-Leibler approximation of spectral densities

We introduce a Kullback-Leibler type distance between spectral density functions of stationary stochastic processes and solve the problem of optimal approximation of a given spectral density Ψ by one that is consistent with prescribed second-order statistics. In general, such statistics are expressed as the state covariance of a linear filter driven by a stochastic process whose spectral density is sought.

Anton Shiriaev, Umeå University, Sweden

Generating and Controlling Stable Walking Patterns in Bipeds

The talk suggests the description of new method for controlling underactuated mechanical systems such as walking mechanisms.
The problem of generating stable walking pattern in bipeds includes two subproblems: motion generation (kicking a ball, exercizing, making a step) and rendering a chosen motion stable (that is feasible in experiments). The current method suggests solution for both subproblems: the first one is solved on a basis of new concept in mechanics - a virtual holonomic constraint; while for the second subproblem the method describes a design procedure for exponential orbital stabilization of any generated motion on the first step. The final feedback controller is time varying and nonlinear. The theoretical contribution of the talk is illustrated by some experimental tests.

Jonas Sjöberg, Chalmers University of Technology, Sweden

Estimating independent parameterized plant and noise models in nonlinear processes: possibilities of using linear model-on-demand in combination with instrumental variable techniques

Most used nonlinear model structures can be described as nonlinear regression models where the regressor contains past input and output values. Such models are also often described as nonlinear ARX models. This class of model structures has algorithmic advantages since the the prediction model, ie, the mapping from the regressor to the output estimate, is a static mapping and there are no stability problems in the estimation algorithm. The draw-back is that the noise model cannot be chosen independent from the plant model and this can be a significant disadvantage if the data is noisy. On the contrary, nonlinear model structures with independent plant and noise models have the disadvantage that the prediction error method (PEM) can become unstable. The computational load of the estimation algorithm is also considerably larger than for nonlinear regression models.

This talk gives a background to the problems described above and presents an alternative to PEM for model structures with independent plant and noise models. It is based on a combination of two established methods: The first method is models-on-demand, a framework where a local linear model is estimated at a point in the regressor space where a prediction is needed. The second method is the instrumental-variable technique, well-known from linear system identification. By first applying a high order models-on-demand an estimate of a noise-free data set is obtained which forms the base for the estimation of the plant and the noise models.

This is joint work with Astrid Lundgren, Chalmers.

Olof Staffans, Åbo Akademi, Finland

Passive and Conservative Infinite-Dimensional Linear State/Signal Systems

We develop the theory of linear infinite-dimensional passive and conservative time-invariant systems in discrete and continuous time. The model that we use is built around a state/signal node, which differs from a standard input/state/output node in the sense that we do not distinguish between input singnals and output signals, only between the state space (the "interior") and the signal space (the "exterior"). Our state/signal model is an infinite-dimensional version of Willems' behavioral model with latent variables interpreted as the state. We first take both the state space and the signal space to be Hilbert spaces, and explain what standard notions, such as existence and uniqueness of solutions, continuous dependence on initial data, observability, controllability, duality, stabilizability, detectability, and stability mean in this setting. Out of these especially our notion of (approximate) controllability seems to be new in a behavioral context. We then replace the signal space by a Krein space, and look more closely at systems that are simple and conservative or minimal and passive. In particular, we construct a minimal balanced passive realization of a given passive transfer function by interpolating half-way between a minimal optimal and a minimal $*$-optimal realization. All of these realizations are unique up to unitary similarity. By looking at a conservative or passive state/signal system from different points of view (i.e., by splitting the signal space into the sum of an input space and an output space in different ways) we recover the well-know scattering, impedance, and transmission input/state/output settings. The family of different scattering (or impedance or transmission) systems that we obtain in this way is the orbit of one fixed scattering system under a linear fractional transformation whose coefficient matrix is J-unitary, where the choice of J depends on the setting. We pay special attention to the case where the transfer function is lossless from one or two sides, connecting this property to the strong one-sided or two-sided stability of the main semigroup of the simple conservative scattering representation, and to the one-sided or two-sided strong conditional stability of the simple conservative state/signal realization.

This is joint work with Damir Arov.