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Graduate Students in Systems and Control

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Abstracts of Presentations

According to presentation order

Ben-Gurion University of the Negev, Mechanical Engineering Dept.
April 20, 2009

Perceptuomotor Transparency in Bilateral Teleoperation

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Abstract

In bilateral teleoperation, the operator holds a local robot which determines the motion of a remote robot and continuously receives delayed force feedback. Transparency is a measure of teleoperation system fidelity. The ideal teleoperator system is the identity channel, in which there is neither delay nor distortion. During the last decades transparency was widely analyzed using two-port hybrid representation of the system in Laplace domain. Such representations define hybrid matrix that maps between the transmission channel inputs and outputs. However, in measuring transparency one should consider also the human operator, and therefore we propose a multidimensional measure of transparency which takes into account: i) Perceptual transparency: The human operator cannot distinguish when the teleoperation channel is being replaced by an identity channel. ii) Local Motor transparency: The movement of the operator does not change when the teleoperation channel is replaced by an identity channel. iii) Remote transparency: The movement of the remote robot does not change when the teleoperation channel is replaced by an identity channel. We hypothesize that by selecting filters and training protocol it is possible to obtain perceptually transparent teleoperation (i) and remote motor transparency (iii) without local motor transparency (ii), namely, to transparentize the system. We formally defined the transparency error, analyzed this process in the linear case, and simulated simplified teleoperation system according to typical experimental results in our previous studies about perception of delayed stiffness. In this simulation we have demonstrated the feasibility of transparentizing process, including tunning of appropriate teleoperation channel paprameters as well as changing the simulated movement to represent training. We believe that these tools are essential in developing functional teleoperation systems.

Robustness to Delay Uncertainties in Sampled-Data Systems

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Abstract

Convex Optimization Approach to Stability of Linear Systems with Uncertain Delays

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Abstract

In this paper we develop a convex optimization approach to stability analysis of systems with interval time-varying delay, by using the standard and the delay-partitioning-based Lyapunov-Krasovskii Functionals (LKFs). We introduce further a novel LKFs with matrices depending on the time-delays. This allows to derive the conditions, which depend on both, the upper and the lower bounds on delay derivatives without using the system or the LKF augmentation. Numerical example illustrates the efficiency of the new stability criteria.

On the Dynamic Resilience and Novel Control Structures for Plants with Multiple Dead Times

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Abstract

Time delays appear in many processes in industry. The presence of the dead times complicates the control design and exerts severe limitations on the performance and dynamic resilience of such systems. Hence control structures that can potentially improve the performance and the dynamic resilience of those processes are of central importance. More than twenty years ago the dynamic resilience of Multi Input Multi Output (MIMO) plants with multiple delays was studied (mainly by Morari and co-workers) and a surprising result that states that in some cases dynamics performance can be improved by artificially increasing delays was arrived at. This result holds to date. To identify plants for which performance can be improved by adding artificial delays a test called the "rearrangement test" was derived and several possible extensions of the well known Single Input Single Output (SISO) Smith Predictor to MIMO stable plants with multiple delays was presented. In this presentation new H^2 optimal structures of dead time compensators (DTC) for MIMO stable/unstable plants with multiple input/output delays, derived recently via extensions of the loop shifting technique, are explored. Through treatment of simpler cases of plants with input delays and output delays it is shown that artificially increasing delays do not necessarily improve performance. It is further demonstrated that the improved resilience gained by the optimal DTCs is due to a novel interchannel feedforward component and that unlike the ad hoc procedures for constructing DTCs and the optimal methods for single delay cases, the structure of the optimal DTC depends on the exogenous inputs and the control goals. Simple examples demonstrate the results.

Robust Simplified Adaptive PI Model Following for Linear Time-Delay Systems With Guaranteed H_∞ Performance

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Abstract

An output-feedback model-following problem is solved, for linear time-varying delay systems with polytopic type parameter uncertainties and disturbances, using a simple direct adaptive control scheme. Sufficient conditions for closed-loop stability, model following performance and prescribed H_∞ disturbance attenuation level of the proposed simplified adaptive control scheme are given, in terms of Bilinear Matrix Inequalities(BMIs). Stability is analyzed using the Lyapunov-Krasovskii functional method, and both delay-dependent and delay-independent results are obtained. The addition of the proportional gain term, that is directly applied to the tracking error (in addition to the traditional integral-type term), reduces the conservatism in the BMIs. The objective is to obtain sufficient conditions for closed-loop stability and guaranteed H_∞ performance of the proposed simplified adaptive control scheme, so that the system output follows the output of the model. The controller does not utilize the knowledge of the delay; only the bounds on the delay and delay-rate are used. Numerical examples are given, which demonstrate the effectiveness of the proposed controller and the simplicity of its implementation.

Analysis of Learning Near Temporary Minima Using the All Permutations Fuzzy Rule-Base

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Abstract

An important problem in learning using gradient descent algorithms (such as backprop) is the slowdown incurred by temporary minima (TM). We consider this problem for a network trained to solve the XOR problem. The network is transformed into the equivalent all permutations fuzzy rule-base which provides a symbolic representation of the knowledge embedded in the network. We develop a mathematical model for the evolution of the fuzzy rule-base parameters during learning in the vicinity of TM. We show that the rule-base becomes singular and tends to remain singular in the vicinity of TM. Our analysis suggests a simple remedy for overcoming the slowdown in the learning process incurred by TM. This is based on slightly perturbing the values of the training examples, so that they are no longer symmetric. Simulations demonstrate the usefulness of this approach for the more general problem of learning the parity function.

Optimal Steady-State Traffic Control for Isolated Intersections

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Abstract

In this paper a simplified isolated controlled intersection is introduced. Discrete-event max-plus model is proposed to formulate the optimization problem for the switching sequences. The formulated max-plus problem is converted to be solved by linear programming (LP). In the special case when the criterion is a strictly increasing and linear function of the queue lengths, the steady-state control problem is solved analytically. Feasibility conditions for the steady-state and N-stages control have been derived.

Optimal Flight Paths for Emergency Landing

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Abstract

Engine cut constitutes a typical emergency situation in General Aviation (GA). In such an emergency, a safe landing trajectory must be found toward a landing strip. When the available landing strip is far, minimizing the energy loss along the trajectory becomes a critical concern. Therefore, this problem should incorporate a dynamic model of the aircraft, rather than a static one. Basic models describe the flight in six dimensions (6D), so the complexity of the problem is very high. This is further compounded by the need to consider ground obstacles and other flight constraints. Existing methods for trajectory generation under dynamic models are not suited for this problem, given the solution should be obtained in the cockpit in a very short time.

We start by formulating the problem as an optimal control problem. The optimality requirement is to minimize the energy loss along the trajectory, under the constraints of flight dynamics and in the presence of geographic and man-made obstacles.

We propose an approximate solution to this problem, which relies on a problem-specific coarse discretization of the 6D state-space. The transition from a continuous problem to a discrete one is performed by employing motion-primitives. These primitives are pre-defined, simple, flight sections that can be easily connected to form a flyable trajectory. This trajectory approximates the optimal trajectory between two states in 6D.

Using the motion-primitives enables coarse discretization of the state-space, while enforcing the dynamic constraints along the trajectory. The discretized model is represented as a graph, whose nodes are the sampled points in the state-space, and the weight along an edge is the energy loss associated with the primitive-generated trajectory. To find the minimum-energy-loss path along this graph, we apply an accelerated derivative of the Dijkstra shortest path algorithm. This efficient algorithm allows fast on-board computation, with limited sub-optimality penalty.

The performance of the proposed solution will be presented for several test cases.

Controllers for Kinematic and Dynamic Models of Mobile Robots: Tracking a Time-Parameterized Path and Driving in Convoy

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Abstract

This study considers control strategies for a wheeled mobile robot model that incorporates the kinematic and dynamic equations of motion. The vehicle model accounts also for the actuator dynamics. Using the backstepping method we propose control schemes for tracking a time-parameterized path. Applications of the tracking controller for driving convoy-like vehicles are considered as well. Finally, simulation results which demonstrate the controller performances are presented.

A White Noise Approach to the Study of Linear Stochastic Systems with Applications

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Abstract

Consider a Gaussian discrete stochastic process that passes through a LTI system. Then the output will be a Gaussian discrete stochastic process as well, and prediction theory for such processes is well developed. But when randomness is allowed in the impulse response that determines the system, the output need not be Gaussian. We wish to attack two problems: first, to ensure that the output stays Gaussian, and next, to develop prediction theory for such processes.

For that purpose we consider the White Noise Space setting, and a multiplication operator (Wick product) which forces Gaussian output. In the WNS there exists an isomorphism (Hermite transform) which translates randomness to functions with infinite number of variables (in the Fock space, or in spaces containing it). The autocorrelation function of a stationary process will be defined by using Wick multiplication operator.

On the H^2 Four-Block Model Matching Problem with Preview

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Abstract

Numerous estimation and control problems fall into the category of problems with information preview. For example, in many communication applications, certain delay between estimation generation and estimated signal is tolerable. In such problems the allowed delay may be interpreted as availability of the future measurements within a constant preview window. Similarly, in some tracking and disturbance attenuation problems, e.g., those arising in active suspension control, robotics, etc., preview of disturbances and/or command signals may be available to the controller. Clearly availability of preview can potentially improve the performance of a controller or an estimator. The questions are how this potential can be evaluated and exploited. It is well know that both control and estimation problems with information preview can be recast to a unified setting, referred to as model matching with preview. The two block version of this problem is currently well studied in both H^2 and H_∞ settings. Many problems of interest, however, such as measured disturbance attenuation, have an intrinsic four-block structure. This motivates our study of the general four-block problem with preview, which, to the best of our knowledge, has not been solved in the literature. It turns out that extension of the existing two-block solutions to the four-block setting is by no mean trivial, and that the difficulties begin already in the stage of the stabilization. Recently, it was shown that under a mild simplifying assumption all stabilizing solutions of the general model matching problem can be characterized by an affine parameterizations in terms of a single parameter[1]. This result is crucial in the context of optimization with preview and serves as a starting point for the current study. In this work we reconsider the stabilization problem, and rewrite the parameterization of all stabilizing solutions in a form suitable for further optimization procedure. This enables us to extend existing methods of the solution of the two-block optimization problem with preview to the general four-block setting. This leads to an efficient and transparent solution of the H^2 four-block problem, which offers an insight into the structure of the resulting controller/estimator and enables to analyze the dependence of the achievable performance on the length of preview. The resulting solution is given in terms of two Sylvester equations, associated with the stabilization, and two algebraic Riccati equations having a clear intuitive interpretation.

[1]This result has been reported at the previous meeting (GSC08) and at MTNS08.

Improved Conditions for Nonquadratic Stability and H_∞ Analysis

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Abstract

Methods for optimal linear quadratic control were developed in the 60s, and provided excellent control solutions for systems with dynamics that is known with very high accuracy. These methods are, however, sensitive to uncertainty of the systems parameters. In light of this drawback, many ways have been offered in the past to deal with uncertainty such as: Robust frequency domain methods(e.g. QFT), adaptive control, Neural networks control, etc. In spite of all the advancement made in those various methods, robust state space control methods, and specifically the celebrated H_∞ control design, have been the most efficient. Regardless of the approach used, all the methods suffer to some extent from overdesign, and it is generally believed that any robust design most entail some overdesign. In the present work we introduce a way to reduce this overdesign. First we apply the method offered in [1] to the stability of uncertain LTV systems whose dynamics is bounded by a polytope. We proceed to offer an improvement of this method which is then combined with the parameter dependant method of [2] that is based on a parameter dependent Lyapunov function and is, to the best of our knowledge, the most effective method, so far, for linear robust analysis and design. Efficient sufficient conditions in terms of linear matrix inequalities are derived for stability and stabilizability via state feedback. These conditions are extended to the case of H_∞ control analysis. The obtained method is demonstrated via an example of robust state feedback control synthesis and a comparison is made with the corresponding results that are achieved by the using quadratic methods [5], and the parameter dependent method of [2].

[1] K. Tanaka, T. Hori, and H.O. Wang, "A multiple Lyapunov function approach to stabilization of fuzzy control systems",IEEE Trans. on Fuzzy Systems, vol. 11, no. 4, August 2003. [2] Skelton and de-Oliveira Perspectives in Robust Control, S. O. Reza Moheimani Ed., Lecture Notes in Control and Information Sciences 268, Springer, London 2001. [3] S. Boyd, L. El Ghaoui, E. Feron and V. Balakrishnan, Linear Matrix Inequalities in System and Control Theory, SIAM, Philadelphia, 1994. [4] C.Scherer ans S.Weiland ,Linear Matrix Inequalities in Control, Delft University of Technology, The Nether- lands 2005. [5] I.R.Petersen ,"Quadratic stability of uncertain linear systems containing both constant and time verying uncertain parameters", J. Optim. Theory Appl. Vol. 57 pp 439-461, 1988. [6] O.Yaniv ,Synthesis of Feedback Systems, Faculty of Engineering, Tel-Aviv University, Israel ,1995.

Finite Nyquist and Finite Inclusions Theorems for Disjoint Stability

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Abstract

Finite Nyquist Theorem is an important tool in stability analysis and design of linear systems. Currently, Finite Nyquist Theorem can treat only simply connected convex stability regions with some extensions to simply connected non-convex regions. In this paper, we consider the generalization of Finite Nyquist Theorem for the case of union of disjoint convex stability regions. Based on this result, the Finite Inclusions Theorem is formulated for union of disjoint convex stability regions.

Periodic Optimization of Planar Systems Makes Sense

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Abstract

We study the infinite horizon problem, where the dynamics are in the plane. We verify that under general assumptions, the optimum is attained by a periodic solution. By this we show that periodic optimization in planar autonomous systems achieves the optimal efficiency. The proof uses (non-differential) geometric ideas.

Real-Time Mosaic-Aided Aerial Navigation

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Abstract

This work presents a method for real-time mosaic-aided aircraft navigation. The method utilizes an on-line mosaic image construction process based on images acquired by a gimballed camera attached to an airborne platform, which scans ground regions in the vicinity of the flight trajectory. The images captured by the camera are used to update the mosaic image while simultaneously estimating the platform's motion.

The presented method fuses mosaic-image-based motion estimation with a standard navigation system, yielding mosaic-aided navigation that does not rely on any a-priori information. The mosaic-based motion estimation uses inter-relations among images captured in real time during flight. This motion estimation is transformed into residual translation and rotation measurements, which are fed into a Kalman Filter, fusing the inertial measurement and the mosaic-based motion estimation. The proposed method can arrest and reduce the secular growth of inertial navigation errors, and correct measurements of the on-board inertial sensors.

The mosaic-based motion estimation, using a scanning camera and a concomitant mosaic construction procedure, provides improved estimation precision in challenging scenarios, such as flight over low-texture scenes captured by a camera with a narrow filed-of-view. We also show that mosaic-aided navigation outperforms traditional vision-based aiding methods in these challenging scenarios. To validate the proposed algorithms, we carried out a comprehensive performance evaluation, involving real imagery and an implementation of the camera scanning and mosaic image construction processes.

The approach proposed in this work is an alternative to Simultaneous Localization and Mapping (SLAM) in the following sense: We assume that the mosaic image construction is an independent process, to be utilized for improving the navigation system. Therefore, the proposed architecture alleviates some of the computational load associated with SLAM.

Network Time Synchronization using Decentralized Kalman Filtering

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Abstract

Accurate clock synchronization is important in many distributed applications, both in wire line and wireless computer networks. Time synchronization between the nodes of a network was extensively treated in the literature, where several methods and algorithms were proposed to solve this problem efficiently. In the Internet for example, the "Network Time Protocol" (NTP) is the most widely accepted standard for clock synchronization. In some recent work, improved algorithms that rely on Least-Squares estimation were introduced. The accuracy of clock synchronization was improved by imposing the global constraints for all the loops in the multihop network and the use of a distributed algorithm employing only local broadcasts. A central characteristic of these methods is their decentralized nature where each node is required to communicate only with its neighbors. In this research, we will extend the Least-Squares framework by developing algorithms that estimate the offset of the local clock at each network's node, using a Kalman Filter framework. We will present a synchronous decentralized implementation of the filtering algorithm that employs only local broadcasts and we will prove that it converges to the optimal centralized solution. The Kalman filter framework allows exploiting some a-priori knowledge and providing different weights to the measurements according to their quality. We will further present a recursive version of these algorithms. Finally, we will extend the results to the estimation of the clock skew (i.e., frequency deviation) in addition to its offset. We also present numerical results on several network topologies for evaluating and comparing the accuracy of the proposed time synchronization schemes.

Two Machines Infinite Bus Power System Dynamic Simulation and Stability Improvement with Wave-Based Control Method PSS

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Abstract

The Single Machine Infinite Bus (SMIB) power system model is an approximation to synchronous generator connected to the utility system trough a transmission line. This model also simplifies the analysis of a number of synchronous generators aggregated together, generally on the same area, connected to another area or to another group of aggregated generators. In case of more the one machine or one group, the power system becomes a multi-machine power system and the analysis become more complicated especially the transients and the dynamics analysis. In this paper we present dynamic simulation results of a two-machine infinite bus power system as a function of the strength of the intertie connecting the two machines. To illustrate graphically this dependency we derive the energy function of the system. Further, we demonstrate the use a novelty method called wave based control used in robotic area to stabilize synchronizing oscillations of two machine-infinite bus power system.

MIMO H_∞ Control of Temperature and Humidity inside Greenhouses Cooled by Fogging Systems

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Abstract

Despite the obvious advantages of fogging systems over more traditional cooling methods for greenhouses, this relatively new technique is not widely applied in practice. The major reason for this is the shortage of advanced control algorithm for controlling the fogging system together with ventilation. This work presents a MIMO control formulation of the temperature and relative humidity tracking problem inside a small experimental greenhouse. The greenhouse actuators consist of variable-speed fans together with two high pressure water lines. By defining the above two actuators to be the control inputs and the outside solar radiation, dry-bulb temperature and relative humidity as the disturbances, a MIMO control problem is formulated and solved under the framework of H_∞ loop shaping optimization technique. This yields a robust multivariable (22) sub-optimal controller which succeeds to maintain the dry-bulb temperature and relative humidity inside the greenhouse within $\pm 2\,^oC$ and $\pm 10\%$ of their respective setpoints.