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Book of Abstracts

L^2 Optimization in Discrete FIR Estimation: How to Outperform Levinson-Durbin

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Abstract

Finite impulse response (FIR) filters might be advantageous over their infinite impulse response (IIR) counterparts in numerous applications. This is mainly because of their numerical stability, robustness to computational errors, and efficient implementation. Another useful property of FIR filters is their limited memory, which may be desirable in applications where abrupt changes in input signals occur.

The mean-square optimal design of FIR filters is currently quite well understood. For example, if the filter is an all zeros filter with $N \in Z^+$ coefficients, its parameters can be found by inverting the so called *autocorrelation* matrix, R_N. As the order of the filter grows, the computational complexity of the inversion of the $N \times N$ autocorrelation matrix clearly increases. When computing, in real time, filters with horizons of several thousands time steps this becomes a real problem. The computational burden can be decreased to $O(N^2)$ by the use of the Levinson algorithm, which exploits the Toeplitz structure of R_N. There are modifications of the Levinson algorithm that can asymptotically achieve even lower computation burden, $O(N \log(N))$, by exploiting the symmetry of R_N and parallel processing.

Intuitively, one may expect that more efficient algorithms exist if there is an additional structure in the signals involve. A possible way to introduce such a structure is to model the signals as outputs of a given system, *G*, driven by a common, normalized, signal. Some papers exploit the state-space structure of *G*, to achieve a computational complexity of $O(N)$.

In this talk, I will present an alternative state-space design of a mean-square optimal FIR filter. The idea is to solve the problem through a static L^2 problem in the lifted domain. The signal generator *G* is not restricted to be stable itself. This is important in handling steady-state requirements. For example, the static gain constraint $G(1) = 1$ can be cast as the stability requirement on the error system in the case when $G(z)$ has a pole at $z = 1$. Thus, the filter is designed with an additional requirement on the stability of the error system from the exogenous signal driving the signal generator, to the error signal. Moreover, the estimator is not restricted to be causal, and the problem is solved for arbitrary preview lengths.

State Estimation in Hybrid Systems with a Bounded Number of Mode Transitions

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Abstract

We consider the problem of tracking the state of a hybrid system capable of performing a bounded number of mode switches. The system is assumed to either follow a nominal model standing for, e.g., the non-maneuvering motion regime of a target, or the fault-free operation mode of a sensor, or obey an anomalous model representing, e.g., the abrupt evasive maneuvers of a target, or the faulty operation of a sensor. Such systems are frequently encountered in target tracking, which is a vital component of any guidance system.

In the case under consideration, the optimal tracking algorithm requires the implementation of a polynomially growing number of primitive Kalman filters. On the other hand, the system's switching dynamics is not Markov because of the a priori bounded number of model switches, thus ruling out direct use of popular estimation schemes such as the IMM and GPB algorithms. We derive an efficient estimation scheme that uses a number of primitive Kalman filters that is linear in the number of possible maneuvers. The scheme resembles the IMM algorithm in that it uses interaction between some of the primitive filters before every estimation cycle, thus reducing the number of such filters. However, due to the specific mode switch dynamics the proposed filter differs from IMM both in structure and operation. Specifically, whereas the IMM algorithm uses each primitive KF to describe each of the possible modes, the proposed filter maintains these KFs as "mode switch counters" in order to be able to track the mode transitions, yielding, at the end, an improved performance by smartly maintaining these KFs.

To demonstrate the superior performance of the algorithm we provide a wide range of examples. The first are simple sanity check cases in which the algorithm is applied directly to the model it is designed for. These cases are followed by a comprehensive Monte Carlo simulation. We conclude by altering the underlying assumptions of the problem and demonstrate excellent performance even in cases significantly deviating from the nominal conditions.

Relative State Estimation of Non-Cooperative Spacecraft Using Stereoscopic Vision

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Abstract

Estimating the relative pose and motion of cooperative spacecraft using on-board sensors is a challenging problem. When the spacecraft are non-cooperative, the problem becomes far more complicated, as there might not be any a priori information about the motion or structure of the target spacecraft. In this work, we address this problem by assuming that only visual sensory information is available. Using two cameras mounted on a chaser spacecraft, the relative state consisting of position, attitude, and rotational and translational velocities is estimated via an EKF-based interlaced filtering scheme. The proposed estimation methodology, which embeds a relative attitude estimator that is tailored for the problem at hand, sacrifices adequate statistical modeling for attaining filtering consistency. As distinct from common methods for incorporating functional relations among states, which typically require heavy, possibly ad-hoc, tuning procedures, our approach naturally handles the set of nonlinear constrains originating from the underlying spacecraft rigidity assumption. The performance of the new filtering algorithm is demonstrated based on an extensive Monte-Carlo simulation.

Linear State Space Theory in the White Noise Space Setting

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Abstract

In the classical studies of state space equations, the system parameters are assumed deterministic. We will introduce a different approach allowing the parameters of the system to be random in some sense. In order to achieve that we introduce the Kondratiev space of distributions, S_{-1}. The Kondratiev distribution space contains Gaussian random variables. In his space two fundamental tools are used, the Wick product and Hermite transform, both in terms of the Hermite functions basis representation.

The extended state space equations when randomness is allowed in the system are written by replacing the standard multiplication with the Wick multiplication, with elements assumed to be of the appropriate sized matrices with entries in S_{-1}.

In this framework the transfer function of a series $(h_n)_{n \in \mathbb{N}}$ is given by

$$\mathcal{H}(\zeta, z) = \sum_{n=0}^{\infty} \zeta^n \big(\boldsymbol{I}(h_n)\big)(z) = \mathbf{D}(z) + \zeta \mathbf{C}(z)\big(I_N - \zeta \mathbf{A}(z)\big)^{-1}\mathbf{B}(z), \qquad (1.1)$$

The topology in $\boldsymbol{I}(S_{-1})$ ensures that one can choose ζ small enough such the extended transfer function is well defined.
The image of the Kondratiev space under the Hermite transform, denoted by $\mathfrak{R}$, is a commutative ring without divisors of zeros (that is, a domain). It is not Noetherian, so most results in system theory on commutative rings cannot be applied. Still, it has a very important property, which allows us to proceed. An $\mathbf{F} \in \mathfrak{R}$ is invertible in $\mathfrak{R}$ if and only if its constant coefficient is non zero. More generally, for $p \in \mathbb{N}$, an $\boldsymbol{F} \in \mathfrak{R}^{p \times p}$ will be invertible in $\mathfrak{R}^{p \times p}$ if and only if the matrix $\mathbf{F}(0)$ (which belongs to $\mathbb{C}^{p \times p}$) is invertible. A major feature in our approach is the observation that key characteristics of a linear, time invariant, stochastic system are determined by the corresponding characteristics associated with the deterministic part of the system, namely its average behavior. For instance, assume that the realization

$$\mathcal{H}(\zeta, 0) = \mathbf{D}(0) + \zeta \mathbf{C}(0)\big(I_N - \zeta \mathbf{A}(0)\big)^{-1}\mathbf{B}(0), \qquad (1.2)$$

is observable. Then realization (1.1) is observable. Furthermore, the realization problem has been studied. That is, we formulate the necessary and sufficient conditions for a given function $\mathcal{H}(\zeta, z)$ to admit a realization of the form (1.1) with coefficients matrices having entries in $\mathfrak{R}$.

Finally, since the ring $\boldsymbol{I}(S_{-1})$ is a domain with non-invertible elements, we can also conclude that the known duality principle doesn't hold in this case.

Near-Optimal Missile Guidance with Pulse-Motor Control Logic

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Abstract

This study deals with the planar non-linear guidance problem for an interception missile. The model includes several non linearities; a) geometry (large deviations from the collision course);b) aerodynamic forces as function of the angle of attack and velocity, c) an axial two pulse rocket motor enabling ignition of the 2nd pulse on demand; and d) a change in mass. The proposed solution method is based on the formulation of the problem as a switched system consisting of four stages with predetermined order. The stages are a) initial boost after launch; b) first coast stage after first pulse burnout; c) second pulse after controlled firing of the second pulse; and d) second coast phase after second pulse burnout. The duration of the first coast phase is controllable on tine and can be zero. The duration of the final cost stage is a result of previous decisions and can be zero as well. The optimal solution is based on the minimum principle as formulated for switched systems. As the optimal solution of the problem is complicated and not suitable for on-line real-time applications, A near optimal solution using the singular perturbation method is presented allowing a real time solution. The optimal problem definition includes the hard constraint of ideal interception (achieving impact with the target) while optimizing a function that compromises minimum flight time and maximal terminal kinetic energy. Minimum flight time is critical in military missions (in anti-aircraft missions it means less chance of weapon release by the enemy, in other missions it gives a second intercept chance). The importance of maximal terminal kinetic energy is also significant, allowing higher end game maneuvers and lethality (in kinetic energy interceptors). In order to solve this problem, a new condition in the minimum principle was derived. The condition regards switched systems with system equations dependent on the switching time. The solution method used results in a simple to implement analytic solution to the problem.

Cooperative Guidance Strategies for an Aircraft–Defending Missile Team

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Abstract

Optimal cooperative pursuit-evasion strategies, for a team composed of two agents, are derived. The specific problem of interest is that of protecting a target aircraft from a homing missile. The target aircraft performs evasive maneuvers and launches a defending missile to intercept the homing missile. The problem is analyzed using a linear quadratic differential game formulation, for arbitrary order linear players' dynamics, in the continuous and discrete domains. Perfect information is assumed. The solution of the game provides: 1) the optimal cooperative evasion strategy for the target aircraft; 2) the optimal cooperative pursuit strategy for the defending missile; 3) the optimal strategy of the homing missile for pursuing the target aircraft and for evading the defender missile. The obtained guidance laws are dependent on the zero effort miss distances of two pursuer-evader pairs: homing missile - target aircraft, and defender missile - homing missile. Conditions for the existence of a saddle point solution are derived and the navigation gains are analyzed for various limiting cases. Nonlinear two-dimensional simulation results are used to validate the theoretical analysis. The advantages of cooperation are shown. Especially, compared to a conventional one-on-one guidance law, cooperation significantly reduces the maneuverability requirements of the defending missile.

Modeling, Identification and Robust Control Design of a Laboratory Helicopter

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Abstract

This talk addresses modeling and control of a 3DOF low-cost laboratory helicopter, controlled through adjusting the speed of its two propellers. The challenges are highly nonlinear dynamics, unreliable components, and the instability of the open-loop system. A linear design model of the helicopter is obtained by combining physical modeling, open- and closed-loop identification of system components, and linearization techniques. This results in a 2-input (armature voltages of two DC motors) and 3-output (pitch, roll, and yaw) system with non-negligible inter-channel couplings.

A two-loop controller design procedure is proposed. The inner loop is closed on the pitch and roll angles using the H-inf loop shaping design procedure. To this end, decoupling and PI weighting functions are used to render the design more transparent and to guarantee the presence of an integral action in the controller. The outer loop is then closed on the yaw angle using the roll angle as its control input. The designed controller is experimentally validated.

Limit Cycle Existence Condition in Control Systems with Backlash and Friction

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Abstract

Backlash and friction effect on limit cycle existence is preliminarily investigated for the basic one-mass, 2nd order and two-mass non-linear servo systems with simplified models of Coulomb friction and backlash. By the describing function method, it is shown that the lower boundary for limit cycle existence, in the backlash gap [rad] - dry friction moment [Nm] plane, is a straight line starting in the origin. Besides, a novel condition is formulated for this system to avoid limit cycle excitation for any combinations of dry friction and backlash gap. This condition can be valuable for control systems design with fully unknown or uncertain values of backlash gap and dry friction.

Sampled-Data Stabilization of a Class of Parabolic Systems

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Abstract

Consider the following semilinear scalar heat equation

$$z_t(x, t) = a\, z_{xx}(x, t) + \beta(z(x, t), x, t)\, z(x, t) + u(x,t)\ ,\ x \in [0,\pi], \qquad (1)$$

coupled to the Dirichlet boundary conditions $z(0, t) = z(\pi, t) = 0$; where subindexes denote the corresponding partial derivatives and where $\alpha > 0, \beta$ is a smooth and bounded function $|\beta| \leq \beta_0$ $u(x,t)$ is control input. It is well-known that a linear infinite-dimensional feedback $u(x,t) = -Kz(x, t)$ with big enough $K > 0$ exponentially stabilizes the system [2]. For realistic design, finite-dimensional discrete version realizations [1], [5] may be applied.

Our objective is to design an exponentially stabilizing sampled-data controller:

$$u(x,t) = -Kz(x_j,t_k);\ x_j \leq x < x_{j+1};\ j = 0,\ldots,N\text{-}1,\ t \in [t_k; t_{k+1}),\ \ k = 0,1,2 \ldots \quad (2)$$

where $0 = x_0 < x_1 < \ldots < x_N = \pi$ with $x_{j+1} - x_j \leq \Delta,\ 0 < h_0 \leq t_{k+1} - t_k \leq h$. By using the direct Lyapunov method we derive sufficient conditions for exponential stabilization in terms of Linear Matrix Inequalities (LMIs). We note that an LMI approach to distributed parameter systems has been recently introduced in [3], [4].

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Explicit Construction of the Barabanov Norm for the Discrete–Time Planar Positive Absolute Stability Problem

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Abstract

We consider the discrete--time absolute stability problem with a planar and positive linear system in the feedback loop. This is equivalent to analyzing the stability under arbitrary switching of a planar switched system switching between two positive subsystems. We provide a solution of this problem via explicit construction of the corresponding Barabanov norm. Surprisingly, perhaps, the unit circle in the Barabanov norm is just a parallelogram. To the best of the authors' knowledge this is the first time that a closed--form expression for the Barabanov norm of a discrete--time switched system is derived.

Analysis of Discrete-Time Linear Switched Systems: A Variational Approach

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Abstract

A powerful approach for analyzing the stability of continuous-time switched systems is based on using tools from optimal control theory to characterize the "most unstable" switching law. This reduces the problem of determining stability under arbitrary switching to analyzing stability for the specific "most unstable" switching law. More generally, this so-called variational approach was successfully applied to derive nice-reachability-type results for both linear and nonlinear continuous-time switched systems. Motivated by this, we develop an analogous approach for discrete-time linear switched systems. We derive and prove a necessary condition for optimality of the "most unstable" switching law. This yields a type of discrete-time maximum principle (MP). We demonstrate using an example that this MP is in fact weaker than its continuous-time counterpart. To overcome this, we introduce the auxiliary system of a discrete-time linear switched system, and show that regularity properties of time-optimal controls for the auxiliary system imply nice-reachability results for the original discrete-time linear switched system. Using this approach, we derive several new Lie-algebraic conditions guaranteeing nice-reachability results. These results, and their proofs, turn out to be quite different from their continuous-time counterparts.

Stability Analysis of Networked Control Systems: a Discontiuous Lyapunov Functional Approach

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Abstract

This paper presents a new stability analysis of linear networked control systems. The new method is inspired by discontinuous Lyapunov functions that were introduced in [1] and [2] by using impulsive system representation of the sampled-data and of the networked control systems respectively. In the recent paper [3] piecewise-continuous (in time) Lyapunov-Krasovskii functionals have been suggested for the stability analysis of sampled-data systems in the framework of input delay approach. Differently from the existing Lyapunov functionals for systems with time-varying delays, the discontinuous ones can guarantee the stability under the sampling which may be greater than the analytical upper bound on the constant delay that preserves the stability. The objective of the present paper is to extend the discontinuous Lyapunov functional approach to networked control systems, where the sampling and the network-induced delays are taken into account. Our results depend on the upper bound of the network-induced delay and the improvement is achieved if the latter bound becomes smaller.

References:
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Robust Stability and Stabilization of Linear Switched Systems with Dwell Time

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Abstract

Sufficient conditions are given for the stability of linear switched systems with dwell time and with polytopic type parameter uncertainty. A Lyapunov function, in quadratic form, which is non-increasing at the switching instances is assigned to each subsystem. During the dwell time, this function varies piecewise linearly in time after switching occurs. It becomes time invariant afterwards. This function leads to asymptotic stability conditions for the nominal set of subsystems that can be readily extended to the case where these subsystems suffer from polytopic type parameter uncertainties. The method proposed is then applied to stabilization via state-feedback both for the nominal and the uncertain cases.

Simple Adaptive H_∞ Control for Linear Systems with Delayed Measurements

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Abstract

An output-feedback direct adaptive control problem is considered for a class of linear time delayed measurements systems with polytopic-type parameter uncertainties and disturbances. The objective is to make the system output follow the output of a system model and to attain guaranteed H_∞ performance of the proposed adaptive control scheme. Since coping with such uncertainties with fixed controllers may involve considerable conservatism, compensating for the uncertainties using adaptive control seems a reasonable approach. The time-delay is either constant (known) or time-varying. In both cases, the problem is tackled by applying a combination of a simple direct adaptive control scheme, a Smith-predictor, and a low-pass filter. Although a few robust and simpler versions of Smith-predictor modifications have been proposed, no rigorous treatment for general plants with polytopic uncertainties and uncertain time-delay has been suggested. Sufficient conditions for closed-loop stability, model following performance and prescribed H_∞ disturbance attenuation level of the proposed control scheme are given, in terms of bilinear matrix inequalities. Two numerical examples are given, which demonstrate the applicability of the proposed methods and the simplicity of their implementation.

Optimal Traffic Light Control

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Abstract

A continuous dynamical model of a simplified controlled isolated intersection is derived in order to find and analyze an optimal control policy to minimize total delay. An analytical solution of the optimal control problem with constrained signal light control is presented. The optimal synthesis is found for the four principal control constraint cases. Previous results from the nineteen sixties and seventies are discussed.