GSC'08:
Graduate Students in Systems and Control

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Presentation Abstracts

According to presentation order

School of Electrical Engineering
Tel Aviv University
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Adaptive aggregation for reinforcement learning with efficient exploration in deterministic domains

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Abstract

We propose a model-based learning algorithm, the Adaptive Aggregation Algorithm (AAA), that aims to solve the online, continuous state space reinforcement learning problem in a deterministic domain. The proposed algorithm uses an adaptive state aggregation approach, going from coarse to fine grids over the state space, which enables to use finer resolution in the "important" areas of the state space, and coarser resolution elsewhere. We consider an on-line learning approach, in which we discover these important areas on-line, using a confidence intervals exploration technique. Polynomial learning rates in terms of mistake bound (in a PAC framework) are established for this algorithm, under appropriate continuity assumptions.

Integral sliding mode approach to adjustment of high-order sliding-modes

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Abstract

Sliding modes are used in control theory in order to remove system uncertainties. The idea is to keep a properly chosen constraint by means of high-frequency control switching. The method features insensitivity to external and internal disturbances and very high accuracy. Its drawbacks are dangerous vibrations (the so-called chattering effect), and applicability only when the constraint has the first relative degree. In other words the control is to appear already in the first total time derivative of the constraint function with a non-zero coefficient.

Unfortunately, this invariance is absent during the reaching phase of the sliding-mode control, i.e. before the constraint is established. Integral sliding mode was proposed about 10 years ago to exclude the reaching phase. The idea is to maintain a specially designed constraint in an extended phase space, which is satisfied from the very beginning and in finite time turns into the originally chosen constraint. Since a standard (1st-order) sliding mode is used, the constraint needs to have the first relative degree. Also the chattering problem persists.

Integral sliding mode approach is extended to arbitrary-order sliding modes, removing the relative degree restriction. Any transient dynamics can be prescribed to high-order sliding-modes. The resulting controller is capable to control the output of any smooth uncertain single-input single output system of a known permanent relative degree and is robust with respect to measurement errors and small delays. The control smoothness can be deliberately increased without loss of convergence, practically removing the chattering effect. Simulations confirm the feasibility of the approach.

H_∞ sampled data control of systems with time-delays

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Abstract

Sampled-data H_∞ control of linear systems with state, control and measurement constant delays is considered. The sampling of the controlled input and of the measured output is not assumed to be uniform. The system is modelled as a continuous-time one, where the controlled input and the measurement output have piecewise-continuous delays. The input-output approach to stability and L_2-gain analysis is applied to the resulting system. The discretized Lyapunov functional method is extended to the case of multiple delays, where the Lyapunov functional is complete in one of the delays (in the state) and is simple in the other delays (in the input and in the output), which are unknown, time-varying with known upper-bounds. Solutions to the state-feedback and the output-feedback H_∞ control problems are derived in terms of Linear Matrix Inequalities.

Robust stabilization of an unmanned motorcycle

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Abstract

This work presents a robust control scheme that stabilizes a radio-controlled motorcycle over a wide range of speeds. The design of the controller is based on linearized equations of motion derived using the Newtonian approach and assuming small roll angles. Based on these equations a robust cascade control loop that stabilizes the motorcycle over the desired range of speeds was designed using Quantitative Feedback Theory (QFT). Stabilization was achieved by measuring only the roll angle and its rate of change, and controlling the steering torque. The approach has been validated via simulations and implemented on a radio-controlled scooter. The experiments demonstrated the ability of the controller to stabilize the system.

Visual tracking: a particle filter/template matching approach

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Abstract

Visual tracking is an important task that has received a lot of attention in recent years. Robust general tracking tools are of major interest for applications ranging from surveillance and security to image guided surgery. In these applications, the objects of interest may be translated, rotated, and scaled. Many of the algorithms available tend to be application-specific, are appropriate for a very limited class of video sequences, and suppose strong prior information on the tracked target (e.g., shape, texture, color, camera dynamics, or motion constraints). On the other hand, a number of more generic target visual tracking algorithms search for distinctive features that can be followed from frame to frame. For these reasons, any progress on general arbitrary target (without distinctive features) trackers will be of interest for active vision, recognition, and surveillance applications. In this talk, we consider the problem of tracking arbitrary targets in video sequences. We propose a video tracking framework for tracking non-articulated (blob-like) targets, which lack prominent features. The proposed algorithm work in a variety of scenarios and deal naturally with clutter and noise in the scenes, target deformations (including scaling), partial target occlusions (for a short time), and low contrast targets. With this framework, we achieve robust tracking results.

Efficient reinforcement learning in parameterized models

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Abstract

Learning rates of Reinforcement Learning algorithms critically depend on the efficient exploration of the state and action spaces. Recently several algorithms that employ efficient exploration techniques were introduced and proven to possess learning rate metrics that are polynomial in the model size. In absence of prior knowledge regarding the model structure or parameters, learning time grows at least linearly in the size of the state and action spaces. However, this limitation may be overcome if prior information is known, as is often the case.

In this paper we consider Reinforcement Learning in the parameterized problem, where the model is known to belong to a parameterized family of Markov Decision Processes (MDPs). We further impose here the strong assumption that set of possible parameters is finite, and consider the discounted return problem.

We propose an on-line algorithm for learning in such parameterized models, dubbed the Parameter Elimination (PEL) algorithm, and analyze its performance in terms of the the total mistake bound criterion (also known as the sample complexity of exploration). The algorithm relies on Wald's Sequential Probability Ratio Test to eliminate unlikely parameters, and uses an optimistic policy for effective exploration. We establish that, with high probability, the total mistake bound for the algorithm is linear (up to a logarithmic term) in the size of the parameter space, independently of the cardinality of the state and action spaces.

Sensor fusion of GPS with omni-directional image registration for off-road autonomous vehicle path tracking

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Abstract

One of the main methods in use today for finding a vehicle location is by GPS (Global Positioning System) or DGPS (Differential Global Positioning System). These systems can identify the location of a vehicle to an accuracy of less than 1 meter (DGPS) in optimal conditions.

The accuracy obtained by (D)GPS is in many cases not sufficient to navigate an off-road trajectory. Therefore most (D)GPS based systems are complemented with methods that compensate the regular GPS errors, such as odometer readings or an Inertial Navigation Unit (INU) that work in conjunction with the GPS. The INU itself has high accuracy, at best of centimeters. However, INU is accurate only for short periods of time, and relies on external references for calibration, e.g. the GPS, or if possible, planned stops of the vehicle, whereby it is known that the true velocity is zero.

However there are situations when the GPS accuracy seriously deteriorates for significant periods of time (where we note that a few minutes are a long time), and the INU is in a state that it cannot compensate for the GPS errors. These situations demand emergency or auxiliary methods that are not influenced by the GPS inaccuracy and are applied in emergency situations, i.e. in situations that may not have occurred if the GPS/INU readings were correct. The auxiliary control system suggested here is based on a vision sensor along with path detection algorithms that may recognize the characteristics of an off-road path such as road boundary detection, road width estimation near the vehicle location, road-car relative orientation (position and azimuth angle), and road characteristics in front of the vehicle along the upcoming calculated path, such as a road junction, curves, etc.

The uniqueness of the solution lies in its vision sensor: an omni-directional lens with a high resolution digital camera. The wide field of view grants us a better scene context understanding and larger amount of data to rely on when estimating road characteristics.

The omni-directional lens offers us not only the view of the vehicle's front, but also side views and the rear view of the vehicle, which in turns results in better estimation of vehicle position and orientation on the path. The real time, locally extracted data

from the vision sensor may be used for an auxiliary control loop that will work in conjunction with the main GPS/INU based trajectory control. The vision system may obviously also be used for obstacle detection.

With the use of image registration techniques with aerial photos or a map of the area, it is also our intention to integrate the vision sensor with the GPS outputs, using sensor fusion techniques. In such a way, the total position error may be substantially decreased, and in fact, the GPS will be calibrated in real time.

Probability-guaranteed full-order and reduced-order robust H_∞ filtering

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Abstract

This presentation addresses the problem of robust H_∞ filtering under the requirement that the filtering performance level is attained with a prescribed probability. The problem setup is one of a robust H_∞ Linear Time-Invariant (LTI) filter synthesis for an affinely parameter-dependent LTI system. However, a truncated parameter-box (which represents a probability less than one) is sought, over which the polytopic performance goal is best (and certainly better than the one attainable for the original parameter box).

The solution is based on a new result in which a filtering-type Linear Matrix Inequality (LMI) formulation of the Bounded-Real Lemma (BRL) is derived, which guarantees an upper-bound on the disturbance effect on the estimation error for the robust filter design problem. The approach applies vertex-dependent Lyapunov functions and provides general full-order stationary filtering estimates that outperform the results that have been achieved in the past; filters of reduced-order are also obtained. The search for an appropriate truncated parameter-box, which has recently been used for probabilistic performance analysis and state-feedback control problems, leads to Bi-Linear Matrix Inequalities (BLMIs). These BLMIs are solved iteratively. A uniform distribution is assumed for all the system parameters. The probability requirement is expressed, by recursively using a reduction lemma, as a set of simple LMIs; these LMIs need to be concurrently solved with the above BLMIs. The features of the proposed approach are demonstrated via an example.

On the parameterization of stabilizing solutions to general four-block model matching problems

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Abstract

In this work we study the stabilization problem for the general four-block model matching setup. Namely, our goal is to find whether there exists a stable K, which stabilize the system $T = G_1 - G_3KG_2$ for some given not necessarily stable G_1, G_2, G_3, and then characterize all such K and all the resulting stabilized T. Stabilization problems of this kind arise in a wide spectrum of control and estimation problems, were they correspond to the resolution of asymptotic behavior constraints. The emphasis in this work is placed on finding a convenient parametrization of all stabilizing K and the resulting T. Our main motivation for this comes from the analysis of problems with preview, were resolving stability issues before the preview element is handled could be advantageous.

For two-block model matching problems a complete parameterization of stabilizing solutions is available, which enables to reduce the given two-block model matching setup to a similar–in terms of the structure and complexity–setting with stable data. Yet many preview control problems of interest cannot be reduced to the two-block setting. This motivates the study of the general four-block problem. Analysis of problems related to stabilization of the general four-block model matching setup can be traced back to at least late 70's. To the best of our knowledge, however, existing parameterizations are either implicit or result in expressions, which are considerably more complicated than the original problem.

A key element of the approach proposed in this work is a mild and intuitive assumption which greatly facilitates the treatment. We assert that this assumption is not restrictive in most applications. At the same time, it enables to establish a parameterization of stabilizing solutions, compatible with that available for the two-block problem. In particular, our solution demonstrates that, similarly to the two-block case, resolving constraints imposed by the stability requirement does not increase the problem complexity.

Mathematical modeling of the λ switch: a fuzzy logic approach

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Abstract

Gene regulation plays a central role in the development and functioning of living organisms. Developing a deeper qualitative and quantitative understanding of gene regulation is an important scientific challenge.

The λ switch is commonly used as a paradigm of gene regulation. Verbal descriptions of the structure and functioning of the λ switch have appeared in biological textbooks. We apply fuzzy modeling to transform one such verbal description into a well-defined mathematical model.

The resulting model is a piecewise-quadratic second-order differential equation. It demonstrates functional fidelity with known results while being simple enough to allow a rather detailed analysis. Properties such as the number, location, and domain of attraction of equilibrium points can be analyzed analytically. Furthermore, the model provides a rigorous explanation for the so-called stability puzzle of the λ switch.

Robust induced L_∞ norm optimization of linear parameter varying systems

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Abstract

Parameters variations are part of many real life control problems. The present research is motivated by path following problems for UAV [1], in which the parameters variations are caused by a time-varying reference trajectory. When the latter time variation is slow enough and the state-space representation of the linearized system is affine in the parameters, the problem becomes one of designing a robust controller for a linear system with polytopic uncertainties using a time-invariant Lyapunov function. When the measurement noise can be neglected and there is full access to the state-vector (consisting of, in our case, the cross-track, along track and azimuth angle errors), the problem reduces to a state-feedback controller design.

The relevant disturbance signals (such as sideslip) are magnitude-bounded rather than energy-bounded [2]. This is the motivation for replacing the synthesis method of the (robust) controller from induced L_2 norm (H_∞) to induced L_∞ norm. We first solve the analysis problem, where the induced L_∞ norm of a linear system with polytopic uncertainties is characterized using Linear Matrix Inequalities (LMIs) and a parameter-dependent Lyapunov function [3]. In the synthesis stage we solve the state-feedback problem, using the key lemma of the previous (analysis) stage.

The theory of this work is demonstrated on analysis and synthesis problems motivated by the path following application we have in mind.

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A loop shifting technique for multiple delay MIMO systems

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Abstract

Time delays appear in many processes in industry, economics, biology, flow of information in the internet etc. The presence of dead times complicates the control design for such systems mainly due to the fact that such systems are infinite-dimensional.

A multiple delay MIMO (multi-input multi-output) system in a general linear fractional transformation (LFT) framework is depicted in Fig. 1 where P is the rational part of the generalized plant having multiple input delays, D_α, and multiple

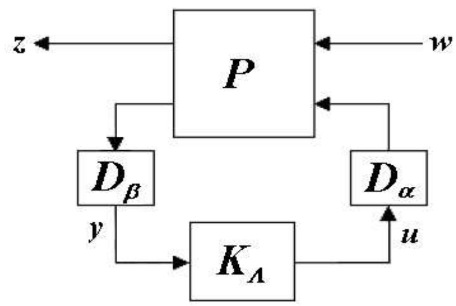

Figure 1: LFT setup.

output delays, D_β, interconnected with a (proper) controller K_Λ. One possible way to simplify the design of K_Λ is to extract the delays from the feedback and from the generalized plant P by loop-shifting and to arrive at an equivalent system for which the design of the controller reduces to a finite-dimensional one. This approach simplifies considerably the design of controllers for such systems and particularly the design of optimal H_2 controllers. Such a loop shifting technique was introduced recently for single delay systems only. It enabled the parametrization of all stabilizing dead time controllers for such systems and revealed the intrinsic structures of such controllers. In this work the loop shifting technique is extended to multiple delay MIMO systems in the LFT setup of Fig. 1. It is shown that this technique converts the original system in Fig. 1 to an equivalent one with delay free feedback and generalized plant such that the stability and signals' energies are preserved. A by product of this technique is that it suggests new structures for MIMO dead time compensators.