Scanning the Issue*

Moments of Random Variables: A Systems-Theoretic Interpretation
Alberto Padoan and Alessandro Astolfi

This paper investigates connections between moments of random variables and moments of dynamical systems. Moments of random variables admitting a probability density function are characterized through Sylvester equations and steady-state responses. This fact is used to reinterpret classical notions and results from probability theory in the language of systems theory, including the notion of moment generating function, the sum of independent random variables, the notion of mixture distribution, and results from renewal theory. Several examples and applications to identifiability, queueing theory, and the approximation of probability density functions are presented.

Reinforcement-Learning-Based Adaptive Optimal Exponential Tracking Control of Linear Systems With Unknown Dynamics
Ci Chen, Hamidreza Modares, Kan Xie, Frank L. Lewis, Yan Wan, and Shengli Xie

Reinforcement learning has been successfully employed as a powerful tool in designing adaptive optimal controllers. Recently, off-policy learning has emerged to design optimal controllers for systems with completely unknown dynamics. However, current approaches for optimal tracking control design either result in bounded tracking error, rather than zero tracking error, or require partial knowledge of the system dynamics. Moreover, they usually require to collect a large set of data to learn the optimal solution. To obviate these limitations this paper applies a combination of off-policy learning and experience replay for output regulation tracking control of continuous-time linear systems with completely unknown dynamics. It is shown that the proposed control method stabilizes the closed-loop tracking error, and gives an explicit exponential convergence rate for the output tracking error. Simulation results show the effectiveness of the proposed approach.

Robust Multitask Formation Control via Parametric Lyapunov-like Barrier Functions
Dongkun Han and Dimitra Panagou

This paper discusses the control of multiagent systems subject to communication and measurement uncertainties, where the goal is to achieve a desired formation while avoiding collisions and maintaining connectivity under uncertainty in the formation’s topology. The authors address this multitask control problem by first providing necessary and sufficient conditions for checking the connectivity of uncertain topologies. Following that, they introduce so-called parametric Lyapunov-like barrier functions which enable the robust, distributed, multitask control of the formation using bounded inputs. The effectiveness of the proposed approach is demonstrated via simulations.

Stochastic Stability of Perturbed Learning Automata in Positive-Utility Games
Georgios C. Chasparis

This paper presents a stochastic stability analysis for a class of reinforcement-based learning. An alternative methodology to the standard ODE-approximation is introduced. This allows analyzing asymptotic convergence through a direct characterization of the invariant probability measure of the induced Markov chain. A methodology for computing the invariant probability measure in positive-utility games is provided. This allows for analyzing convergence in games without the structural assumption of the existence of a potential function. An illustration of this methodology is provided in the context of coordination games.

On the Structure and Computation of Random Walk Times in Finite Graphs
Andrew Clark, Basel Alomair, Linda Bushnell, and Radha Poovendran

The time for a random walk to reach a target set is of interest in understanding the convergence of Markov processes and applications in control, machine learning, and social sciences. In this paper the commute, hitting, and cover times are shown to have submodular structure, even in nonstationary random walks. A unifying proof of these structures is provided by considering each of these times as special cases of stopping times. This framework is generalized to Markov decision processes. Polynomial-time approximation algorithms for choosing target sets are provided.

A Graphical Characterization of Structurally Controllable Linear Systems With Dependent Parameters
Fengjiao Liu and A. Stephen Morse

This paper studies the structural controllability of parameterized linear systems in which a parameter may appear in multiple locations within the systems’ coefficient matrices. Any such system is “structurally controllable” if it is controllable for almost all values of its parameters. Subject to a certain constraint on a system’s parameterization called the “binary assumption,” a necessary and sufficient graph-theoretic condition is derived for determining whether such a system is structurally controllable.

Global Phase and Magnitude Synchronization of Coupled Oscillators With Application to the Control of Grid-Forming Power Inverters
Marcello Colombino, Dominic Gross, Jean-Sébastien Brouillon, and Florian Dörfler

This paper explores a new approach to synchronization of coupled oscillators. In contrast to the celebrated Kuramoto model, the authors do not work in polar coordinates and do not consider oscillations of fixed magnitude. A synchronizing feedback based on relative state information and local measurements that induces consensus-like
dynamics is proposed. The combination of the synchronizing feedback with a decentralized magnitude control law renders the oscillators’ almost globally asymptotically stable with respect to set-points for the phase shift, frequency, and magnitude. The results are applied to rigorously solve an open problem in control of inverter-based ac power systems.

**Analysis and Synthesis of MIMO Multiagent Systems Using Network Optimization**

Miel Sharf and Daniel Zelazo

This paper studies the analysis and synthesis problems for diffusively coupled networks. We focus on networks comprised of multi-in multi-out nonlinear systems possessing a property we term *maximal equilibrium-independent cyclically monotone passivity* (MEICMP), extending recent passivity results for single-in single-out systems. We prove that the steady-state behavior of networks of MEICMP systems corresponds to minimizers of appropriately defined network optimization problems. This perspective leads to a synthesis procedure for designing network controllers yielding a desired output. We provide examples of networked systems satisfying these properties and demonstrate our results by simulation.

**Rate-Cost Tradeoffs in Control**

Victoria Kostina and Babak Hassibi

This paper derives upper and lower bounds to the fundamental tradeoff between the communication rate and the expected quadratic cost in linear stochastic control. The bounds apply to vector, non-Gaussian, and partially observed systems under a long-term average rate constraint, thereby extending and generalizing an earlier explicit expression for the scalar Gaussian system, due to Tatikonda et al. The bounds are tight for high resolution variable-length quantization. Via a separation principle between control and communication, similar results hold for causal lossy compression of additive noise Markov sources.

**Bearing-Only Formation Tracking Control of Multiagent Systems**

Shiyu Zhao, Zhenhong Li, and Zhengtao Ding

This paper proposes new formation control laws based only on relative bearing information for multiagent systems to track moving target formations, and handles a variety of agent models including single-integrator, double-integrator, and unicycle models. Moreover, numerical simulation and real experimental results to verify the effectiveness of the bearing-only formation control laws are presented.

**On Model-Free Adaptive Control and Its Stability Analysis**

Zhongsheng Hou and Shuangshuang Xiong

This paper proposes a model-free adaptive control (MFAC) approach for a class of SISO unknown discrete-time nonlinear systems. The proposed approach guarantees BIBO stability, error convergence, and internal stability, which are proven through rigorous analysis based on the contraction mapping principle. Classical PID control and adaptive control for linear time-invariant systems are explicitly shown to be special cases of the MFAC approach. Since the proposed MFAC approach only makes use of the measured closed-loop I/O data of the controlled plant, long standing problems in traditional model-based adaptive control systems, such as the presence of unmodeled dynamics and robustness, the accurate modeling and model reduction, and the persistency of excitation condition, can all be avoided.

**PI Controllers for One-Dimensional Nonlinear Transport Equation**

Jean-Michel Coron and Amaury Hayat

We introduce a method to obtain necessary and sufficient stability conditions for systems governed by one-dimensional nonlinear hyperbolic partial-differential equations with closed-loop integral controllers, in the cases in which the linear frequency analysis cannot be used. Both the control input and the measured output are located at the boundaries. The principle of the method is to extract the limiting part of the stability from the solution using a projector on a finite-dimensional space and then use a Lyapunov approach.

**Input-to-State Stability of Periodic Orbits of Systems With Impulse Effects via Poincaré Analysis**

Sushant Veer, Rakesh, and Ioannis Poulakakis

This paper extends Poincaré’s analysis for asymptotic stability of limit cycles to establish input-to-state stability (ISS) of such solutions for systems with impulse effects under external excitation. It is shown that ISS of a periodic orbit under external excitation is equivalent to ISS of a zero-input fixed point of the associated forced Poincaré map, enabling robustness analysis of hybrid limit cycles by studying a discrete dynamical system. These results are relevant to robust control design for a broad class of systems exhibiting periodic behaviors, including limit-cycle walking and running robots.