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Editorial

Mathematical Control of Complex Systems

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Recent advances in computing and network technologies have contributed much to the successful handling of certain problems in biology, physics, economics, and so forth that until recently were thought too difficult to be analyzed. These complex systems problems tend to share a number of interesting properties from a mathematical viewpoint. A key feature of such systems is that the nonlinear interactions among its components can lead to interesting emergent behavior.

The overall aim of this special issue is to bring together the latest/innovative knowledge and advances in mathematics for handling complex systems, which may depend largely on methods from artificial intelligence, statistics, operational research, and engineering, including nonlinear dynamics, time series analysis, dynamic systems, cellular automata, artificial life, evolutionary computation, game theory, neural networks, multi-agents, and heuristic search methods. The solicited papers in this special issue should provide solutions, or early promises, to modeling, analysis, and control problems of real-world complex systems, such as communication systems, process control, environmental systems, intelligent manufacturing systems, transportation systems, and structural systems. Topics include, but are not limited to: (1) control systems theory (behavioural systems, networked control systems, delay systems, distributed systems, infinite-dimensional systems and positive systems), (2) networked control (channel capacity constraints, control over communication networks, distributed filtering and control, information theory and control, and sensor networks), and (3) stochastic systems (nonlinear filtering, nonparametric methods, particle filtering, partial identification, stochastic control, stochastic realization, and system identification).

We have solicited submissions to this special issue from electrical engineers, control engineers, mathematicians, and computer scientists. After a rigorous peer review process, 29 papers have been selected that provide overviews, solutions, or early promises, to manage, analyze, and interpret dynamical behaviours of complex systems. These papers have covered both the theoretical and practical aspects of complex systems in the broad areas of dynamical systems, mathematics, statistics, operational research, and engineering.

Recently, there have been significant advances on analysis and synthesis of complex systems with randomly occurring incomplete information. In the paper entitled "*A review on analysis and synthesis of nonlinear stochastic systems with randomly occurring incomplete information*" by Z. Wang et al, the focus is to provide a timely review on the recent advances of the analysis and synthesis issues for nonlinear stochastic systems with randomly occurring incomplete information. In the context of systems and control, incomplete information refers to a dynamical system in which knowledge about the system states is limited due to the difficulties in modeling complexity in a quantitative way. The well-known types of incomplete information include parameter uncertainties and norm-bounded nonlinearities. Recently, in response to the development of network technologies, the phenomenon of randomly occurring incomplete information has become more and more prevalent. Most commonly used methods for modeling randomly occurring incomplete information are summarized. Based on the models established, various

filtering, control and fault detection problems with randomly occurring incomplete information are discussed in great detail. Such kind of randomly occurring incomplete information typically appears in a networked environment, which includes randomly occurring uncertainties, randomly occurring nonlinearities, randomly occurring saturation, randomly missing measurements, and randomly occurring quantization. Subsequently, latest results on analysis and synthesis of nonlinear stochastic systems with randomly occurring incomplete information are reviewed. Finally, some concluding remarks are drawn and some possible future research directions are pointed out.

During the past decades, the problems of stability analysis and stabilization synthesis of complex systems have received significant attentions. In the paper entitled "*Almost sure stability and stabilization for hybrid stochastic systems with time-varying delays*" by H. Shu et al., the almost sure stability analysis and stabilization synthesis problems are investigated for hybrid stochastic delay systems. The stability conditions are presented such that the underlying systems are almost sure stable. Following the same idea as in dealing with the stability problem, the linear state feedback controllers are designed such that the special nonlinear or linear closed-loop systems are almost sure stable. The explicit expressions for the desired state feedback controllers are given in terms of the solutions to a set of linear matrix inequalities. Two simulation examples are given to illustrate the effectiveness of the theoretical results. The stability analysis and semistability theorems are given in "*Semistability of nonlinear impulsive systems with delays*" by Y. Gao and X. Mu for delay impulsive systems. A set of Lyapunov-based sufficient conditions is proposed to guarantee the desired stability properties. In the paper entitled "*Stabilization of time-varying system by controllers with internal loop*" by C. Shi and Y. Lu, the concept of stabilization with internal loop is given for infinite-dimensional discrete time-varying systems in the framework of nest algebra. A parameterization of all stabilizing controllers with internal loop is proposed. It is shown that the strong stabilization problem can be completely solved in the closed-loop system with internal loop. Moreover, the problem of controller design is studied in "L_∞ *control with finite-time stability for switched systems under asynchronous switching*" by R. Wang et al. for switched systems under asynchronous switching with exogenous disturbances. It is shown that the switched system is finite-time stabilizable under asynchronous switching satisfying the average dwell-time condition. Furthermore, the problem of L_∞ control for switched systems under asynchronous switching is also investigated. Finally, a numerical example is given to illustrate the effectiveness of the proposed method.

The design of controller has long been the main stream of research topics and much effort has been made for complex systems. In the paper entitled "*MPC schemes guaranteeing ISDS and ISS for nonlinear (time-delay) systems*" by L. Naujok and S. Dashkovskiy, new directions in model predictive control (MPC) are introduced. The input-to-state dynamical stability and MPC are combined for the single and interconnected systems. The MPC schemes are employed to ensure the input-to-state stability of single systems and networks with time delays. Subsequently, the robust finite-time H_∞ control is studied in "*Robust finite-time* H_∞ *control for impulsive switched nonlinear systems with state delay*" by Z. Xiang et al. for a class of impulsive switched nonlinear systems with time-delay. By employing the piecewise Lyapunov function, sufficient conditions are developed to ensure the finite-time boundedness of the impulsive switched system. In the work entitled "*Robust anti-windup control considering multiple design objectives*" by G. Sun et al., a unified synthesis method of the construction of multi-objective and robust antiwindup controller is proposed for linear systems with actuator saturations, time-varying parametric, and dynamic uncertainties. The analysis and synthesis conditions are developed in terms of the scaled linear matrix inequalities. The impulsive neutral second-order stochastic functional evolution equations are investigated in "*Controllability of second-order semilinear impulsive stochastic neutral functional evolution equations*" by Y. Ding et al. By using the Sadovskii fixed point theorem and the theory of strongly continuous cosine families of operators, the sufficient conditions for the controllability of the system are given. Based on the mean and the standard deviation of lead time demand, in the paper entitled "*Distribution-free continuous review inventory model with controllable lead time and setup cost in the presence of a service level constraint*" by B.-B. Qiu and W.-M MA, the joint decision problem of continuous review inventory is studied.

Networked control systems (NCSs) have attracted much attention owing to their successful applications in a wide range of areas. Accordingly, the design of controller for NCSs has attracted considerable attention. In the paper entitled "*Linear matrix inequalities in multirate control over networks*" by A. Cuenca et al., the networked induced phenomena of bandwidth constraints and time varying delays are considered. Some stability conditions and a state feedback controller design are proposed. Two practical examples are given to illustrate the usefulness of the theoretical results. By utilizing probability-dependent Lyapunov method, the problem of gain-scheduled control is studied in "*Probability-dependent static output feedback control for discrete-time nonlinear stochastic systems with missing measurements*" by G. Wei et al. for a class of discrete time stochastic systems with infinite-distributed delays and missing measurements. A time-varying Lyapunov functional dependent on the missing probability is constructed with hope to improve the performance of the gain-scheduled controller. A static output feedback controller with scheduled gains is designed. In the work entitled "*Observer-based stabilization of stochastic systems with limited communication*" by J. Wu et al., the problem of observer-based stabilization is investigated in stochastic nonlinear systems with limited communication. The phenomena of network-induced delays, data packet dropouts, and measurement quantization are considered. A new stability condition is derived for the stochastic nonlinear system and the design procedure of observer-based controller is given. In the paper entitled "*Finite-time boundedness and stabilization of networked control systems with time delay*" by Y. Sun et al., the finite-time control problem is studied for a class of networked control systems with time delay. Sufficient conditions are given to ensure the finite-time boundedness

and stabilization of the underlying systems. By using the Lyapunov stability theory and discrete Halanay inequality, the exponential synchronization is addressed in "*Exponential synchronization analysis and control for discrete-time uncertain delay complex networks with stochastic effects*" by T. Wang et al.for a class of discrete-time uncertain complex networks with stochastic effects and time delay. Some synchronization criteria and two control methods are obtained.

In the past decades, the issue of parameter estimation has received considerable research interests and has found successful applications in a variety of areas. In the paper entitled "*MIMO LPV state-space identification of open-flow irrigation canal systems*" by A. Grau et al., by identification in a local way using a multimodel approach, a linear parameter-varying (LPV) state-space canal control model is obtained. This LPV identification procedure is based on subspace methods for different operating points of an irrigation canal covering the full operation range. Different subspace algorithms are compared. Subsequently, the parameter estimation problem is studied in "*Asymptotic parameter estimation for a class of linear stochastic systems using Kalman-Bucy filtering*" by H. Shu et al. for a general class of linear stochastic systems. The Kalman-Bucy linear filtering is used to solve the parameter estimation problem. The asymptotic convergence of the estimator is investigated by analyzing Riccati equation and the strong consistent property is studied by comparison theorem. In the work entitled "*Uniform approximate estimation for nonlinear nonhomogenous stochastic system with unknown parameter*" by X. Kan and H. Shu, the error bound in probability between the approximate maximum likelihood estimator (AMLE) and the continuous maximum likelihood estimator (MLE) is investigated for nonlinear nonhomogenous stochastic system with unknown parameter. The rates of convergence of the approximations for Ito and ordinary integral are introduced. Based on these results, the probabilistic rate of convergence of the approximate log likelihood function to the true continuous log-likelihood function is studied for the nonlinear nonhomogenous stochastic system involving unknown parameter. Finally, the error bound in probability between the ALME and the continuous MLE is given. In the paper entitled "*D-Optimal design for parameter estimation in discrete-time nonlinear dynamic systems*" by Y. Liu et al., an optimal input design method is presented for parameter estimation of a discrete nonlinear system. In the paper entitled "*Estimation for stochastic nonlinear systems with randomly distributed time-varying delays and missing measurements*" by H. Shu et al., an estimator is designed such that, for measurements missing and distributed time-varying delays, the estimation error system is mean-square stable.

Over the past decades, the observer/filter problems of complex systems have been investigated extensively since they are very useful in signal processing and engineering applications. In the paper entitled "*Robust H_2/H_∞ filter design for a class of nonlinear stochastic systems with state-dependent noise*" by W. Zhang et al., the problem of robust filter design is studied for a class of nonlinear stochastic systems with state-dependent noise. The state and measurement are corrupted by stochastic uncertain exogenous disturbance and the dynamic system is modeled by Ito-type stochastic differential equations. The robust H_∞ filter can be designed in terms of the solution to the linear matrix inequalities. Moreover, a mixed H_2/H_∞ filtering problem is also solved by minimizing the total estimation error energy when the worst-case disturbance is considered in the design procedure. Subsequently, a cascaded sliding mode observer method is given in "*Fault-reconstruction-based cascaded sliding mode observers for descriptor linear systems*" by J. Yu et al. to reconstruct the actuator faults for a class of descriptor linear systems. Based on a new canonical form, a novel design method is presented to discuss the existence conditions of the sliding mode observer. The proposed method is extended to general descriptor linear systems with actuator faults. In the work entitled "*Data-driven adaptive observer for fault diagnosis*" by S. Yin et al., an approach is given for the data-driven design of fault diagnosis system. The proposed fault diagnosis scheme consists of an adaptive residual generator and a bank of isolation observers, whose parameters are directly identified from the process data without identification of complete process model. To deal with normal variations in the process, the parameters of residual generator are online updated by a standard adaptive technique to achieve reliable fault detection performance. After a fault is successfully detected, the isolation scheme will be activated, in which each isolation observer serves as an indicator corresponding to occurrence of a particular type of fault in the process. The thresholds can be determined analytically or through estimating the probability density function of related variables. A laboratory-scale three-tank system is given to illustrate the usefulness of the proposed method.

The applications of various control schemes have received considerable research interests in the past decades. In the work entitled "*Discrete-time multioverlapping controller design for structural vibration control of tall buildings under seismic excitation*" by F. Palacios-Quinonero et al., a computationally effective strategy to obtain multioverlapping controllers via the inclusion principle is applied to design discrete-time state-feedback multioverlapping LQR controllers for seismic protection of tall buildings. The performance of the proposed multioverlapping controllers has been assessed through numerical simulations. In another paper "*Structural vibration control for a class of connected multistructure mechanical systems*" by F. Palacios-Quinonero et al., the aim is to design the control configurations that combine passive interbuilding dampers with local feedback control systems implemented in the buildings. Moreover, the active-passive control configurations can be properly designed for multibuilding systems requiring different levels of seismic protection. The monocular vision is employed in "*Robot navigation control based on monocular images: an image processing algorithm for obstacle avoidance decisions*" by S. Lauria and W. Benn to control autonomous navigation for a robot in a dynamically changing environment. Subsequently, the optimality condition-based sensitivity analysis of optimal control for hybrid systems with mode invariants and control constraints is addressed in "*Optimality condition-based sensitivity analysis of optimal control for hybrid systems and its application*" by C. Song. The derivatives of the objective functional with respect to control variables are established and

a control vector parameterization method is implemented to obtain the numerical solution to the optimal control problems for hybrid system. In the paper entitled "*Robust H_∞ dynamic output feedback control synthesis with pole placement constraints for offshore wind turbine systems*" by H. R. Karimi and I. Bakka, the problem of robust H_∞ dynamic output feedback control design with pole placement constraints is addressed for a linear parameter-varying model of a floating wind turbine. Finally, a novel multiloop is proposed and the multiobjective cooperative intelligent control system is used in "*Neuroendocrine-based cooperative intelligent control system for multiobjective integrated control of a parallel manipulator*" by K. Hao et al. to improve the performance of position, velocity, and acceleration-integrated control on a complex multichannel plant.

Appendix

Accepted Papers according to Fackled Topics

(1) "A review on analysis and synthesis of nonlinear stochastic systems with randomly occurring incomplete information".

Papers on the Topic of Stability. (2) Almost Sure Stability and *Stabilization for Hybrid Stochastic Systems with Time-Varying Delays*.

(3) Semistability of Nonlinear Impulsive Systems with Delays.

(4) Stabilization of Time-Varying System by Controllers with Internal Loop.

(5) L_∞ Control with Finite-Time Stability for Switched Systems under Asynchronous Switching.

Papers on the Topic of Control for Complex Systems. (6) MPC Schemes Guaranteeing ISDS and ISS for Nonlinear (Time-Delay) Systems.

(7) Robust Finite-Time H_∞ Control for Impulsive Switched Nonlinear Systems with State Delay.

(8) Robust Anti-Windup Control Considering Multiple Design Objectives.

(9) Controllability of Second-Order Semilinear Impulsive Stochastic Neutral Functional Evolution Equations.

(10) Distribution-Free Continuous Review Inventory Model with Controllable Lead Time and Setup Cost in the Presence of a Service Level Constraint.

Papers on the Topic of Control over Networks. (11) Linear Matrix Inequalities in Multirate Control over Networks.

(12) Probability-Dependent Static Output Feedback Control for Discrete-Time Nonlinear Stochastic Systems with Missing Measurements.

(13) Observer-Based Stabilization of Stochastic Systems with Limited Communication.

(14) Finite-Time Boundedness and Stabilization of Networked Control Systems with Time Delay.

(15) Exponential Synchronization Analysis and Control for Discrete-Time Uncertain Delay Complex Networks with Stochastic Effects.

Papers on the Topic of Parameter Estimation. (16) MIMO LPV State-Space Identification of Open-Flow Irrigation Canal Systems.

(17) Asymptotic Parameter Estimation for a Class of Linear Stochastic Systems Using Kalman-Bucy Filtering.

(18) Uniform Approximate Estimation for Nonlinear Nonhomogenous Stochastic System with Unknown Parameter.

(19) D-Optimal Design for Parameter Estimation in Discrete-Time Nonlinear Dynamic Systems.

(20) Estimation for Stochastic Nonlinear Systems with Randomly Distributed Time-Varying Delays and Missing Measurements.

Papers on the Topic of Observer/Filter Design for Complex Systems. (21) Robust H_2/H_∞ Filter Design for a Class of Nonlinear Stochastic Systems with State-Dependent Noise.

(22) Fault-Reconstruction-Based Cascaded Sliding Mode Observers for Descriptor Linear Systems.

(23) Data-Driven Adaptive Observer for Fault Diagnosis.

Papers on the Topic of Applications. (24) Discrete-Time Multioverlapping Controller Design for Structural Vibration Control of Tall Buildings under Seismic Excitation.

(25) Structural Vibration Control for a Class of Connected Multistructure Mechanical Systems.

(26) Robot Navigation Control Based on Monocular Images: An Image Processing Algorithm for Obstacle Avoidance Decisions.

(27) Optimality Condition-Based Sensitivity Analysis of Optimal Control for Hybrid Systems and Its Application.

(28) Robust H_∞ Dynamic Output Feedback Control Synthesis with Pole Placement Constraints for Offshore Wind Turbine Systems.

(29) Neuroendocrine-Based Cooperative Intelligent Control System for Multiobjective Integrated Control of a Parallel Manipulator.

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