Guest Editorial for the Special Issue
On General Systems with Network-Enhanced Complexities

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1. Systems with network-enhanced complexities

In recent years, the study of networked control systems (NCSs) has gradually become an active research area due to the advantages of using networked media in many aspects such as the ease of maintenance and installation, the large flexibility and the low cost. It is well known that the devices in networks are mutually connected via communication cables that are of limited capacity. Therefore, some network-induced phenomena have inevitably emerged in the areas of signal processing and control engineering. These phenomena include, but are not limited to, network-induced communication delays, missing data, signal quantization, saturations, and channel fading. It is of great importance to understand how these phenomena influence the closed-loop stability and performance properties.

It should be pointed out that, what a network induces are much more than those already studied. Nowadays large-scale general systems are usually subject to various sorts of complexities such as parameter uncertainties, time-delays, missing measurements, sensor/actuator saturations, signal quantization, information compressing, signal encryptions and nonlinear disturbances. These kinds of complexities, which do exist in a non-networked environment, are becoming even much severer (in terms of their degrees or intensities) with networked systems due mainly to the limited bandwidth and fluctuation of network load. In other words, these kinds of complexities have been greatly enhanced because of the usage of the communication networks. In this case, it would be interesting to examine 1) how the networks have substantial impacts on the complexity and 2) how to analyze/reduce such kind of network-enhanced complexity. Systems with network-enhanced complexities (NEC) have already become an ideal research area for control engineers, mathematicians, and computer scientists to manage, analyze, interpret and synthesize functional information from real-world networked systems.

2. The special issue

This special issue aims to bring together the latest approaches to understanding, estimating and controlling systems with NEC in a quantitative way. Topics include, but are not limited to, the system modelling, parameter identification, state estimation, and systems control with various NEC such as: (1) network-enhanced nonlinearities; (2) network-enhanced uncertainties; (3) network-enhanced time-delays; (4) network-enhanced sensor saturations; (5) network-enhanced actuator/sensor failures; and (6) network-enhanced channel fading.

We have solicited submissions to this special issue from electrical engineers, control engineers, mathematicians, and computer scientists. After a rigorous peer review process, 11 papers have been selected that provide novel advanced and non-traditional methods, solutions, or early promises, to manage, analyze, and interpret dynamical behaviours of systems with network-enhanced complexities. These papers have

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covered both the theoretical and practical aspects of the system modelling, parameter identification, state estimation, and systems control with various NEC.

3. The papers

In the networked world nowadays, signals are typically transmitted through networks which may undergo inevitable network-induced phenomena. This special issue starts with a solution to the reliable guaranteed-cost control problem for a class of time-varying networked systems with NEC. Specifically, in the paper entitled "*Reliable Guaranteed-Cost Control for Networked Systems with Randomly Occurring Actuator Failures and Fading Performance Output*" by J. Hu et al., the reliable guaranteed-cost control problem for a class of time-varying networked systems with randomly occurring actuator failures and fading performance output is presented. The randomly occurring actuator failure, which describes the phenomenon of the actuator failure appearing in a random way, is modeled by a Bernoulli distributed white sequence with a known conditional probability. The fading performance output is characterized by a random variable obeying any discrete-time probability distribution over a known interval. The reliable controller is designed to ensure that an optimized upper bound of the predefined quadratic performance index is guaranteed for the addressed systems in the presence of both the randomly occurring actuator failures and the fading performance output. The desired controller gain is obtained in terms of the solution to a Riccati-like difference equation. A numerical example is provided to illustrate the feasibility and effectiveness of the proposed control scheme.

The estimation problem in sensor network stochastic systems has become an important research topic in the last years due to their significant advantages in practical situations (low cost, simple installation and maintenance, etc.) and their wide application in target tracking, communications, etc. In spite of this advantages, the communication capacity limitations and unreliable network characteristics, may yield random delays, packet dropouts and missing measurements. In the paper "*Optimal state estimation for networked systems with random parameter matrices, correlated noises and delayed measurements*" by R. Caballero-Águila et al., the optimal least-squares state estimation problem is addressed for a class of discrete-time multi-sensor linear stochastic systems with state transition and measurement random parameter matrices and correlated noises. It is assumed that, at any sampling time, as a consequence of possible failures during the transmission process, one-step delays with different delay characteristics may occur randomly in the received measurements. The random delay phenomenon is modeled by using a different sequence of Bernoulli random variables in each sensor. The process noise and all the sensor measurement noises are one-step auto-correlated and different sensor noises are one-step cross-correlated. Also, the process noise and each sensor measurement noise are two-step cross-correlated. Based on the proposed model and using an innovation approach, the optimal linear filter is designed by a recursive algorithm which is very simple computationally and suitable for online applications. The illustrative example shows that the usefulness of the developed filtering algorithm.

As is well known, in many modern engineering domains involving energy systems, chemical industry and communication process, the signal and system always present a characteristics of multi-variables. As such, the study on two dimensional (2-D) systems is significant and, so far, massive achievements related to this issue have emerged. For 2-D systems, though people have begun to realize the necessity of investigating the incomplete observations, the relevant research is still comparatively little from an overall perspective. In the paper "*Reliable H-infinity State Estimation for 2-D Discrete Systems with Infinite Distributed Delays and Incomplete Observations*" by Y. Luo et al., a novel reliable estimation problem is addressed for a class of 2-D discrete linear systems with incomplete observations. The time delays existing in 2-D systems are assumed to be infinitely distributed in the discrete-time domain. Factors leading to incomplete observations include delayed, missing measurements, sensor quantization and saturations. A uniform mathematical model is employed to describe the phenomenon of incomplete observations. A linear state estimator is designed such that the error dynamics is mean-square asymptotically stable, and the steady-state error of the estimation is not more than a prescribed level. Finally, the feasibility of the proposed approach has been confirmed by a numerical simulation. In the paper "*H-infinity Filtering for two-dimensional systems with mixed time delays, randomly occurring saturations and nonlinearities*" by J. Liang et al., the H-infinity filtering problem is addressed for 2-D systems with mixed time delays which comprise both the discrete time-varying delays and the discrete distributed delays in states. Randomly occurring nonlinearities (RONs) and randomly occurring saturations (ROSs) are also considered, respectively, in the state-space model and the measurement output equation to reflect the nonlinear disturbance appearing in a random way and the limited communication capabilities of the sensors. A full-order H-infinity filter is designed such that the H-infinity performance is guaranteed in the simultaneous presence of the mixed tim delays, RONs and ROSs. By utilizing the Kronecker product and the inequality technique, an energy-like function is developed to establish some sufficient criteria under which the filtering error system satisfies the prescribed H-infinity disturbance attenuation performance. Furthermore, explicit expression of the filter parameters is also characterized. Numerical example provided in the end of the paper further demonstrates the effectiveness of the proposed design scheme.

Most existing filter design approaches are established on the ideal assumption that there is a continuous flow of measurement signals without loss of signalling. However, perfect communication is not always possible in many engineering systems especially in a networked environment due to limited bandwidths and network congestion. In the paper "*Robust H-infinity Filtering for Discrete Nonlinear Delayed Stochastic Systems with Missing Measurements and Randomly Occurring Nonlinearities*" by Y. Liu et al., the robust H-infinity filtering problem is investigated for a class of nonlinear discrete time-delay stochastic systems. The system under consideration involves parameter uncertainties, stochastic disturbances, time-varying delays and sector nonlinearities. Both missing measurements and randomly occurring nonlinearities are described via the binary switching sequences satisfying a conditional probability distribution, and the nonlinearities are assumed to be sector-bounded. The problem addressed is the design of a full-order filter such that, for all admissible uncertainties, nonlinearities and time-delays, the dynamics of the filtering error is constrained to be robustly exponentially stable in the mean square, and a prescribed H-infinity disturbance rejection attenuation level is also guaranteed. By using the Lyapunov stability theory and some new techniques, sufficient conditions are first established to ensure the existence of the desired filtering parameters. Then, the explicit expression of the desired filter gains is described in terms of the solution to a linear matrix inequality (LMI). Finally, a numerical example is exploited to show the usefulness of the results derived.

State feedback control is very attractive due to the precise computation of the gain matrix, but the implementation of a state feedback controller is possible only when all state variables are directly measurable. Hence the need for an estimator or observer is obvious to estimate all the state variables by observing the input and the output of the controlled system. While observer design for linear discrete-time systems is a trivial problem, observer design for piecewise linear plant models raises considerable difficulties. On the other hand, in modern vehicles, the control signals from the controllers and the measurements from the sensors are exchanged using a communication network, e.g., Controller Area Network (CAN), among control system components. This brings up a new challenge on how to deal with the effects of the network-induced delays in the control loop. In the paper "*Observer-based predictive controller design with network-enhanced time-delay compensation*" by C.F. Caruntu, a control design methodology is provided based on a Luenberger observer design that can assure the closed-loop performances of a vehicle drivetrain with backlash, while compensating the network-enhanced time-varying delays. This goal is achieved in a sequential manner: firstly, a piecewise linear model of a two inertias drivetrain, which takes into consideration the backlash nonlinearity and the network-enhanced time-varying delay effects is derived; then, a Luenberger observer which estimates the state variables is synthesized and the robust full state-feedback predictive controller based on flexible control Lyapunov functions is designed to explicitly take into account the bounds of the disturbances caused by time-varying delays and to guarantee also the input-to-state stability of the system in a non-conservative way. The full state-feedback predictive control strategy based on the Luenberger observer design was experimentally tested on a vehicle drivetrain emulator controlled through Controller Area Network, with the aim of minimizing the backlash effects while compensating the network-enhanced delays. The proposed control strategy was tested on a real-time simulation test-bench including CAN communications and the results obtained illustrate that the proposed controller has good performances and it meets the required timing constraints.

In signal processing and control areas, the Kalman filter (KF) has been regarded as an efficiently recursive filter to estimate unknown system states by utilizing measurements. However, since undesirable signals with internal states may accumulate, the traditional KF algorithms might suffer from persistent modeling errors or numerical errors. As such, it could take a long time to converge to a real state even though the temporary undesirable errors disappear. To improve its performance, an alternative filter, namely, the receding horizon filter, has been proposed in the past few years. In the paper "*Receding Horizon Filtering for a Class of Discrete Time-Varying Nonlinear Systems with Multiple Missing Measurements*" by D. Ding et al., the receding horizon filtering problem is investigated for a class of discrete time-varying nonlinear systems with multiple missing measurements. The phenomenon of missing measurements occurs in a random way and the missing probability is governed by a set of stochastic variables obeying the given Bernoulli distribution. By exploiting the projection theory combined with stochastic analysis techniques, a Kalman-type receding horizon filter is put forward to facilitate the online applications. Furthermore, by utilizing the conditional expectation, a novel estimation scheme of state covariance matrices is proposed to guarantee the implementation of the filtering algorithm. Finally, a simulation example is provided to illustrate the effectiveness of the established filtering scheme.

Synchronization has long been one of the most fundamental issues in the complex networks and there have been a number of results available in the existing literature. It should be pointed out that, in most of the literature concerning on the synchronization control problem, the coupling strengths among nodes are assumed to be exactly known. However, it is not always true in the real complex networks and the coupling strengths may exhibit some uncertainties due to the effects of the networked environment. On the other hand, it is well known that, in the digitization process, the sampling fashion plays a vital role. Traditionally, periodic sampling is widely used since it is rather convenient for analysis and design of the control systems. However, periodic sampling may inevitably cause a waste of computation resources since the executions of some control tasks are unnecessary. An alternative scheme is the so-called event-triggered control strategy in which the control signal is transmitted only when a specific condition is satisfied and thus the number of control task executions are reduced significantly. In the paper "*Event-triggered Synchronization Control for Complex Networks with Uncertain Inner Coupling*" by Q. Li et al., the event-triggered synchronization control problem is presented for a class of complex networks with uncertain inner couplings. The uncertain inner coupling under consideration is characterized in terms of the interval matrix. In order to save the communication and computation resources, the event-based mechanism is adopted and the event-triggered synchronization control scheme is proposed for the complex networks. First, the event-triggered synchronization control problem is transformed into the exponential stabilization problem for a new class of dynamical systems with multiple delays. Then, by employing the Lyapunov stability theory, a sufficient condition is derived under which the multi-delayed system is exponentially stable. Subsequently, a set of event-triggered synchronization controllers is designed in terms of the solution to a linear matrix inequality that can be solved effectively by using available software. Finally, a numerical simulation example is presented to show the effectiveness of the proposed event-triggered control scheme. In the paper "*Synchronization for Linear Singularly Perturbed Complex Networks with Coupling Delays*" by C. Cai et al., the synchronization problem is investigated for a class of linear singularly perturbed complex network system with coupling delay. The sufficient delay-dependent conditions for the synchronization of the network are established by introducing an equivalent network system with the Lyapunov stability theory. These conditions, which are formulated in terms of linear matrix inequalities, can be solved efficiently by the LMI toolbox of MATLAB. A simulation example is provided to show the validity of the proposed the synchronization conditions of the whole network.

In sensor networks, the limited battery energy, computational power and memory of the sensor nodes are all changeable in a dynamical way. Therefore, parameter uncertainties are ubiquitous when modeling the target plant and the sensor networks. On the other hand, in comparison with conventional time-triggered communication, event-triggering allows a considerable reduction of the network resource occupancy while maintaining the guaranteed filtering performance, avoids some injurious transmission phenomena such as data dropouts and time delay, etc, and extends the lifetime of the services. Therefore, the event-triggered communication mechanism is particularly significant in sensor networks due to its capability of decreasing the unnecessary executions of the systems and saving energy. In the paper "*Event-triggered Robust Distributed*

State Estimation for Sensor Networks with State-Dependent Noises" by H. Dong et al., the event-triggered distributed state estimation problem is presented for a class of uncertain stochastic systems with state-dependent noises and randomly occurring uncertainties (ROUs) over sensor networks. An event-triggered communication scheme is proposed in order to determine whether the measurements on each sensor should be transmitted to the estimators or not. The norm-bounded uncertainty enters into the system in a random way. Through available output measurements from not only the individual sensor but also its neighboring sensors, a sufficient condition is established for the desired distributed estimator to ensure that the estimation error dynamics is exponentially mean-square stable. These conditions are characterized in terms of the feasibility of a set of linear matrix inequalities, and then the explicit expression are given for the distributed estimator gains. Finally, a simulation example is provided to show the effectiveness of the proposed event-triggered distributed state estimation scheme.

The H-infinity control for linear systems was well established since the early 1990s. However, there exist many complex nonlinear dynamic systems that we wish to control, such as chemical reactors, power plants, and others. It is well–known that such systems are very difficult to model and control because of their nonlinearities and uncertainties appearing in practical situations. In the paper "*Discrete-time H-infinity control for nonlinear polynomial systems*" by M. Hernandez–Gonzalez et al., a solution of the suboptimal H-infinity regulator problem is presented for a class of discrete-time nonlinear polynomial systems. The solution is obtained by reducing the H-infinity control problem to the corresponding H_2 one. A general solution has been obtained for a polynomial of an arbitrary order. Then, finite-dimensional regulator equations are derived explicitly for a second order polynomial. Finally, Numerical simulations have been carried out to show effectiveness of the proposed method.

4. Acknowledgement

This special issue brings together the latest approaches to understanding, estimating and controlling systems with NEC in a quantitative way. Finally, we like to acknowledge all authors for their efforts in submitting high-quality papers. We are also very grateful to the reviewers for their thorough and on-time reviews of the papers. Last, but not least, our deepest gratitude goes to Professor George Klir, Editor-in-Chief of *International Journal of General Systems* for his consideration, encouragement, and advice to publish this special issue.

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Guest Editors
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Appendix: Accepted papers in the order they appear in the editorial

1. IJGS01_Jun, Reliable Guaranteed-Cost Control for Networked Systems with Randomly Occurring Actuator Failures and Fading Performance, Jun Hu (contact)
2. IJGS02_Linares-Perez, Optimal State Estimation for Networked Systems with Random Parameter Matrices, Correlated Noises and Delayed Measurements, J. Linares-Pérez (contact)
3. IJGS03_Guoliang, Reliable H-infinity State Estimation for 2-D Discrete Systems with Models Infinite Distributed Delays and Incomplete Observations, Guoliang Wei (contact)
4. IJGS08_Jinling, H-infinity Filtering for Two-Dimensional Systems with Mixed Time Delays, Randomly Occurring Saturations and Nonlinearities, Jinling Liang (contact)
5. IJGS04_Yurong, Robust H-infinity Filtering for Discrete Nonlinear Delayed Stochastic Systems with Missing Measurements and Randomly Occurring Nonlinearities, Yurong Liu (contact)
6. IJGS05_Caruntu, Observer-Based Predictive Controller Design with Network-Enhanced Time-Delay Compensation, Constantin Florin Caruntu (contact)
7. IJGS06_Derui, Receding Horizon Filtering for a Class of Discrete Time-Varying Nonlinear Systems with Multiple Missing Measurements, Derui Ding (contact)

8. IJGS07_Bo, Event-triggered Synchronization Control for Complex Networks with Uncertain Inner Coupling, Bo Shen (contact)
9. IJGS09_Cai, Synchronization for Linear Singularly Perturbed Complex Networks with Coupling Delays, Chenxiao Cai (contact)
10. IJGS10_Hongli, Event-triggered Robust Distributed State Estimation for Sensor Networks with State-Dependent Noises, Hongli Dong (contact)
11. IJGS11_Basin, Discrete-time H-infinity control for nonlinear polynomial systems, M.V. Basin (contact)