Analysis and Design on Hybrid Dynamical Systems: Stability, Control and Filtering

A thesis submitted for the degree of

Doctor of Engineering

Professor Peng Shi

BSc, MSc, PhD (Mathematics), PhD (Engineering), DSc, FIEEE, FIET, FIMA

School of Electrical and Electronic Engineering

The University of Adelaide

Adelaide, SA 5005, Australia

March 24, 2015

Abstract

In order to control the behavior of a system, it is necessary to capture the salient system features in a mathematical model. Dynamic systems are intrinsically difficult due to their system complexities, the challenge of measuring various parameters and also the uncertain and/or time-varying parameters. The development of systematic methods for efficient and reliable design of such complex control systems is a key issue in control technology and industrial information. It is currently of high interest to control engineers, computer scientists and mathematicians in research institutions as well as in many industrial sectors.

In practice, a large class of physical systems has variable structures subject to random changes. These may result from abrupt phenomena such as component and interconnection failures, parameters shifting, tracking, and the time required to measure some of the variables at different stages. Systems with this character may be modeled as hybrid ones, that is, to the continuous state variable, a discrete random variable called the mode, or regime, is appended. The mode describes the random jumps of the system parameters and the occurrence of discontinuities. Such a system model is useful particularly since it allows the decision maker to cope adequately with the discrete events that disrupt and/or change the normal operation of a system significantly, by using the knowledge of their occurrence and the statistical information on the rate at which these events take place.

This thesis is based on my research into hybrid dynamical systems. Most of this research has been conducted through theoretic studies with experiments (either numerical or practical examples) to verify the obtained results, which has great potential for practical applications. Therefore it is wholly consistent with the mission of the university from which I seek this degree award.

Statement of Originality

This thesis does not contain material that has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, the thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

Dedication and Acknowledgments

My parents came from farming families of remote countryside China. In their time, children helped their family with laboring and thus they did not even have the opportunity to complete their primary school education. However, they realized the importance of education after they started their careers later on and put their best effort they possibly could on me, my two sisters (both completed their university education in China) and a brother (he completed his PhD in engineering from Japan and now works there as a professor). As a gesture of respect and gratitude, I wish to dedicate this Application for DEng to my parents, Jinche Shi and Deyun Zou.

My wife Fengmei Sun and two children, Bo and Michael, have blessed me with consistent and strong support throughout my career development. Their love and patience has always inspired me to continue achieve one goal after another, including my two PhDs, a DSc, and this DEng submission. I have always felt stronger and more confident as I feel my whole family is behind me. Without their care and support, all the achievements I have obtained would not be possible. I am very grateful to them indeed.

I would like also to thank my PhD student, Mr Fanbiao Li, for his help in putting all my submitted publications together.

Last, but not the least, I greatly appreciate all my co-authors of the publications submitted for their contributions in our ongoing collaborations and lasting friendship.

Contents

1. INTRODUCTION

The publications in this Application are submitted as evidence of work "of high distinction" which makes "an original and significant contribution" to the advancement and application of knowledge, as required by the University's regulations for higher doctorates. Evidence is also provided to establish that I am a "leading authority in the field of study concerned".

The academic discipline of "Systems and Control" has attracted much attention and has made strong developments in the last three decades. Since commencing a life of academia in 1985, I have fully participated in the advancement of this field through research, scholarship programs, academic publishing and professional society services, all of which form the basis for this Application for Doctor Degree of Engineering.

This Application is based on my research since 2006 under Systems and Control. It is entitled *Analysis and Design on Hybrid Dynamical Systems: Stability, Control and Filtering*. Most of this research has been conducted through theoretic studies with numerical simulations or practical examples to verify the obtained results. Prospective practical applications include networked control systems, power systems, manufacturing systems, communication systems, etc. Thereby being wholly consistent with the mission of the university from which I seek this degree award. This is also consistent with the citation: *for contributions to control and filtering techniques for hybrid dynamical systems*, when I was elevated to IEEE Fellow in 2014.

Like most academic subjects, control and filtering have a number of facets or themes, some of which reflect the origin of the subject, and others which have emerged comparatively recently. My own work has focused on the following four themes:

1. Fuzzy control systems: A fuzzy control system is a control system based on fuzzy logical mathematical model that analyzes analog input values in terms of logical variables.

2. Neural networks: An artificial neural network is an interconnected group of nodes, akin to the vast network of neurons in a brain. Here, each circular node represents an artificial neuron and an arrow represents a connection from the output of one neuron to the input of another.

3. Stochastic systems: Stochastic system is the one whose state is random so that the subsequent state of the system is determined probabilistically.

4. Networked control systems: A feedback control system wherein the control loop is closed through a real-time network.

Many of my results on the above topics have been published in a number of leading international journals in my discipline, such as Automatica; SIAM Journals; IEEE Transactions (including Automatic Control; Circuits and Systems; Systems, Man and Cybernetics; Fuzzy Systems; Neural Networks; Industrial Electronics; Industrial Informatics; Automation Science and Engineering; Aerospace and Electronic Systems); etc. From a total of some 200 publications in research monographs, international journals, book chapters and conference proceedings, I have selected 3 books and 65 journal papers, which I believe can best reflect my research achievements on the above four themes. The work presented demonstrates my ability as an internationally recognized leading researcher in my specialist subject.

Following this Introduction, I have given a statement pertaining to the "nature and significance of the work submitted". By way of providing specific amplification of the publications themselves, I have given a list of the 3 books and 65 papers with a brief abstract, and then an explanation of their authorship. To provide broader evidence that I am a leading authority in my subject, I have included a summary of my professional career. Cover pages from the 3 books and 65 publications will form the remainder of this Application.

2. STATEMENT OF THE NATURE AND SIGNIFICANCE OF THE WORK SUBMITTED

The basis of my Application for Doctor degree of Science is that I have made a sustained and significant contribution to the development of analysis and design on hybrid dynamical systems, more precisely, fuzzy systems, neural networks, stochastic jump systems, and networked control systems. The quality of my publications, together with other professional services and activities, demonstrates that I have become recognized as a leading authority in my field of study.

The publications are arranged in four of the major themes of the subject, as explained in the Introduction, and these are summarized below together with an explanation of the context of the research.

2.1 Introduction of hybrid dynamical systems

The term hybrid systems are used in the literature to refer to systems that feature an interaction between diverse forms of dynamics. Most heavily studied in recent years are hybrid systems that involve the interaction between continuous and discrete dynamics. The study of this class of systems has, to a large extent, been motivated by applications to embedded systems and control. Embedded systems by definition involve the interaction between digital devices and a predominantly analog environment. In optimal control problems, it is typically assumed that a cost is assigned to the different runs of the hybrid system. The objective of the controller is then to minimize this cost by selecting the values of the control variables appropriately. Typically, the cost function assigns a cost to both continuous evolution and discrete transitions. Let us take a predictive control model of power electronics as example. Power electronic systems are used to transform electrical power from one, usually unregulated form, to another regulated one. This transformation is achieved by the use of semiconductor devices that operate as power switches, turning on and off with high switching frequency. The whole system is a hybrid one, since the discrete switch positions are associated with different continuous-time dynamics. Other examples include direct torque control of three-phase induction motors; optimal control of fixed frequency switch-mode de-dc converters; command and control in military operations; communication systems; and flexible manufacturing systems, etc.

2.2 Fuzzy modeling, control and filtering

Publications 1-16

Fuzzy sets and systems have gone through substantial development since the introduction of fuzzy set theory by Zadeh *et al.* [1, 2]. They have found a great variety of applications ranging from control engineering, qualitative modelling, pattern recognition, signal processing, information processing, machine intelligence, decision making, management, finance, medicine, motor industry, robotics, and so on [3–6]. In particular, fuzzy logic control, as one of the earliest applications of fuzzy sets and systems, has become one of the most successful applications. In fact, fuzzy logic control has proven to be a successful control approach to many complex nonlinear systems or even nonanalytic systems. It has been suggested as an alternative approach to conventional control techniques in many cases.

Based on the differences of fuzzy control rules and their generation methods, approaches to fuzzy logic control can be roughly classified into the following categories: i) Conventional fuzzy control; ii) fuzzy proportional-integral-derivative (PID) control; iii) neuro-fuzzy control; iv) fuzzy-sliding mode control; v) adaptive fuzzy control; and vi) Takagi-Sugeno (T-S) model-based fuzzy control. However, it should be noted that the overlapping among these categories is inevitable. For example, conventional fuzzy control can be adaptive, fuzzy PID control can be tuned by neuro-fuzzy systems, or neuro-fuzzy control is adaptive in nature in many cases.

T-S fuzzy model [7], also called the Type-III fuzzy model by Sugeno [8], is in fact a fuzzy dynamic model. This model is based on using a set of fuzzy rules to describe a global nonlinear system in terms of a set of local linear models which are smoothly connected by fuzzy membership functions. This fuzzy modelling method offers an alternative approach to describing complex nonlinear systems [9–11], and dramatically reduces the number of rules in modelling higher order nonlinear systems [8]. Consequently, T-S fuzzy models are less prone to the curse of dimensionality than other fuzzy models. More importantly, T-S fuzzy models provide a basis for development of systematic approaches to stability analysis and controller design of fuzzy control systems in view of powerful conventional control theory and techniques.

A great number of theoretical results on function approximation, stability analysis, and controller synthesis have been developed for T-S fuzzy models during the last twenty years. T-S fuzzy models are shown to be universal function approximators in the sense that they are able to approximate any smooth nonlinear functions to any degree of accuracy in any convex compact region [12, 13]. This result provides a theoretical foundation for using T-S fuzzy models to represent complex nonlinear systems approximately. Based on the differences of design approaches, the methods for stability analysis and control design of T-S fuzzy systems can be roughly classified into the following four categories: i) simple local controller design and stability checking [14, 15]; ii) stabilization with/without various performance indexes such as H_2 and H_∞ control based on a common quadratic Lyapunov function [16, 17]; iii) stabilization with/without various performance indexes based on a fuzzy Lyapunov function [18,19]; and iv) adaptive control when parameters of T-S fuzzy models are unknown [20, 21].

My work on fuzzy systems has made significant contributions in solving the following problems, which are not only important in theory, but also potentially useful in practical systems analysis, modeling and design:

- Some sufficient conditions are derived for the stability and some optimal performances by developing new techniques for T-S fuzzy systems with time-delays. The proposed methodologies include the fuzzy Lyapunov-Krasovskii functional approach, the delay-partitioning approach, the small gain theorem based input-output approach, and the reciprocally convex approach, etc. The main aim by using these advanced approaches is to effectively reduced the conservatism of the obtained results, thus facilitate the design subsequently. Then, some optimal synthesis problems, including the stabilization, the dynamic output feedback controller (DOF) design, the robust H_∞ filtering, and the model approximation, are investigated based on the analysis results.

- The parallel theories and techniques developed are extended to deal with T-S fuzzy stochastic systems. A unified framework under 'stochastic stability' is established for analyzing T-S fuzzy stochastic systems. Specifically, the main focus is on stochastic stability analysis, stabilization, l_2-l_∞ DOF control, H_∞ filtering, fault detection and model approximation problems for T-S fuzzy stochastic systems. Sufficient conditions are established for the stochastic stability and optimal performances of the continuous- and discrete-time T-S fuzzy stochastic systems. Based on the obtained analysis results, the optimal synthesis issues are addressed.

- A set of newly developed techniques (e.g., the fuzzy Lyapunov-Krasovskii functional method, the linear matrix inequality (LMI) technique, the cone complementary linearization approach, the slack matrix approach, and the sums of squares technique) are exploited to handle the emerging mathematical and computational challenges.

2.3 Neural networks: analysis and design

Publications 17–31

Neural networks (NNs) have received increasing attention in recent years, since NNs have found successful applications in various areas ranging from associative memory and pattern recognition to medical diagnosis and data mining due to their strong capacity to handle formidable problems and to improve system performance.

Approaches based on recurrent neural networks for solving optimization problems, which use analog computation implemented on electronic devices to replace numerical computation realized by mathematical algorithms, have attracted considerable attention (see, for example, [22–29], and the references therein) However, due to the existence of many equilibrium points of recurrent neural networks, spurious suboptimal responses are likely to be present [30–35] which limit the applications of recurrent neural networks. Thus, the global asymptotic/exponential stability of a unique equilibrium point for the concerned recurrent neural networks is of great importance from a theoretical and application point of view [36, 37].

Research on the stability of recurrent neural networks in the early days was for symmetric recurrent neural networks with or without delays. Recently, the work in [38] investigates the exponential stability of delayed recurrent neural networks with Markovian jumping parameters. The results in [38] motivate us to study the stability analysis on NNs whose parameters operate by a switching signal, that is, the switched NNs. It should be noted, here, that the switching is arbitrary over average dwell time, but not in the form of Markovian switching as proposed in [38]. The motivation to study such systems is twofold. Firstly, from a practical point of view, switching among different system structures is an essential feature of many real-world systems, such as, chemical processes, transportation systems, computer controlled systems and communication industries. Secondly, from a control point of view, multi-controller switching provides an effective mechanism to cope with highly complex systems and/or systems with large uncertainties, for example, many intelligent control strategies are designed based on the idea of switching controllers to improve the system performances [39]. However, the results reported on the arbitrary switching NNs are very limited. In fact, investigating such problem is generally difficult due to the fact that the probability distribution of switching is not available. Many open problems still remain unsolved. For example, conditions are needed to guarantee the stability of the switched NNs when it changes from one mode to another under arbitrary switching. Such work should be interesting and challenging since it integrates the switched hybrid systems into that of the NNs, and thus theoretically significant.

The problem of exponential stability analysis is investigated for continuous-time switched NNs. By using the average dwell time approach and the piecewise Lyapunov function technology, together with a novel Lyapunov-Krasovskii function (LKF) which benefits from the delay partitioning method with free-weighting matrix technique, sufficient conditions are proposed to guarantee the exponential stability for the switched NNs with constant and time-varying delays, respectively, and the decay estimates are explicitly given. The results reported are not only dependent on the delay but also dependent on the partitioning, which will reduce the conservatism. The applicability of the derived analytical results is exemplified by several illustrative examples in comparison with the existing results.

My main contributions of analysis and design of neural networks are summarized as follows:

- The receding horizon stabilization problem for neural networks with time-varying delay is formulated and, based on this formulation, a new sufficient condition on the terminal weighting matrices of a new cost functional is proposed. An LMI condition for the receding horizon disturbance attenuation of neural networks with time-varying delay and disturbance is presented.

- An unideal measurement model is established, which is capable of covering both quantization and missing measurements phenomena in a unified way by using two Bernoulli distributed white sequences with known conditional probabilities. Sufficient conditions are presented under which the filtering error system is stochastically stable and the H_∞ performance requirement is satisfied.

- A dynamic surface control approach is successfully applied to nonlinear stochastic systems, which avoids repeated differentiating the virtual controller by introducing a first-order filter in each step of backstepping design procedure. Furthermore, a direct adaptive radial basis function NNs control method is proposed, where the number of adaptation parameters is only one, which significantly reduces the computation burden. Furthermore, the developed controller design is independent of any prior knowledge of NNs.

2.4 Control and filtering on stochastic hybrid systems

Publications 32–50

A large class of physical systems have variable structures subject to random changes, which may result from the abrupt phenomena such as component and interconnection failures, parameters shifting, tracking, and the time required to measure some of the variables at different stages. Systems with this character may be modeled as hybrid ones, that is, the state space of the systems contains both discrete and continuous states. Among this kind of systems, jumping systems have been a subject of great practical importance which has attracted a lot of interest for last three decades. In jumping systems, the dynamics of the discrete and continuous states are modeled, respectively, by a finite state Markov chain and linear differential equations subject to the discrete process.

Stability properties of systems described by multiple models switching according to Markov chains can be analyzed via the notion of stochastic stability introduced in [40]. When parameters of Markov chain describing the transition between different models are not completely known, it is important to know how much uncertainty can be tolerated for the system to be stochastically stable. In [41], the problem of almost sure instability has studied of the random harmonic oscillator.

In order to ensure the performance of MJSs, many techniques have been proposed, for example, linear quadratic control theory [40], H_2 control theory [47,48], H_∞ control theory [49–52], H_∞ filtering theory [53–55], and so on by defining accordingly performance index. Since its introduction in 1980s, the so-called H_∞ optimal control has been one of the most attractive and dominated research topics in the past 30 years [56]. As is well known, filtering technique has been playing an important role in a variety of application areas including signal processing, target tracking, and image processing. Up to now, many important developments on the filtering problem have been made for MJSs. The designed filters can be classified into two types: mode-dependent filters ([57,58]) and mode-independent filters ([59–61]).

In practice, it is difficult to obtain the exact value of the switching probabilities. For instance, in the soft landing process of a reentry body [42], the probability of opening the parachute is determined by the altitude as well as its rate of change. Another example refers to internet based networked control systems, where the packets dropouts and channel delays can be modeled by Markov chains [43], but the delay or packet loss is distinct at different periods, which leads to the resulting transition probability (TP) matrix changing throughout the running time. Similar phenomenon also arises in other systems, such as electronic circuits, mental health analysis, and manpower systems. To overcome the above issues, MJSs with uncertain transition probabilities have been studied in [44–46], in which robust approaches were adopted to cope with some compact sets with polytopic-type or norm-bounded structure in the transition probability matrix.

My main contributions on stochastic hybrid systems are as follows:

- Developed robust algorithms (design procedure) for control and estimation for systems with Markovian jump parameters (linear/nonlinear systems in the presence of parameter uncertainties). The controller would guarantee the resulting closed-loop system to be robustly stochastically stable and satisfying a prescribed performance, irrespective of admissible uncertainties. While filter design method was proposed such that the dynamics of the estimation error is robustly stochastically stable and is less than a prescribed value.

- Several versions of the strict bounded real lemma for continuous time systems with finite discrete jumps were developed. The bounded real lemma derived was in terms of a Riccati differential equation, or inequality, with finite discrete jumps. It was shown that our result is a "unified treatment" of continuous time and discrete time bounded real lemmas, i.e. these bounded real lemmas are special cases of our result. It laid a foundation for control and filtering design for sampled-data systems.

- A design procedure of controllers for sampled-data systems which guarantee both stability and a prescribed H_∞ performance was developed. The performance measure we used is the worst-case gain from the disturbances, which includes the disturbance input, measurement noise and unknown initial state, to the controlled output. This output comprises both a continuous-time and a discrete-time signal. Control problems on both finite and infinite horizon are addressed. Necessary and sufficient conditions for the existence of a suitable H_∞ sampled-data output feedback controller were given in terms of two Riccati differential equations with jumps.

- A complete solution to the H_∞ filtering problem for a class of uncertain continuous-time systems under sampled measurements was obtained. The class of uncertain systems is described by a linear state space model with unknown cone-bounded nonlinearity in the state equation and time-varying norm-bounded parameter uncertainty in the state and output matrices. We addressed the problem of designing linear filters which guarantee a prescribed performance, irrespective of the uncertainties and unknown nonlinearity. The performance measure we used is of the H_∞ type and involves both the estimation error for the continuous-time and discrete-time signals. It has been shown that the above robust H_∞ sampled-data filtering problem can be solved in terms of two Riccati-like equations.

2.5 Investigation on networked control systems

Publications 51–65

In a number of emerging engineering applications, the measurement and control commands need to be sent over communication networks, which bring considerable and varying transmission times. Typical examples can be seen in the remote control of several mobile units, arrays of microactuators, underwater acoustic, and even neurobiological and social-economical systems. A typical feature in these systems is that time division multiplexed computer networks are employed for exchanging information between spatially distributed plant components. Motivated by these emerging engineering applications, in recent years more and more attention has been drawn to the development of a general theory for networked control systems (NCSs), which considers control and communication issues simultaneously.

Due to its great advantages (such as low cost, reduced weight and power requirements, simple installation and maintenance, and high reliability), great effort has been denoted to NCSs. Therefore, modeling, analysis, and control of network-based systems with limited communication capability has emerged as a topic of significant interest to the control community. Among the vast literature on NCSs that is available to date, we refer the readers especially to the books [62–64], survey papers [65], special issues [66–68], PhD dissertations [69,70], and the numerous references therein to see the state-of-the-art in NCSs. The stability of NCSs has been investigated in [71] and [72] where networked induced delays are taken into consideration for the stability analysis. The control problem has been addressed in a number of papers. To mention a few, a sampled-data approach has been developed to design state-feedback controllers which considers the network induced delays and data-packet dropouts simultaneously in the control design with or without performance requirements [73,74]; stochastic approaches have been proposed by using various stochastic descriptions about the network induced delays or data packet dropouts [75,76]; and a moving horizon control strategy has been reported in [77]. The problem of estimation has been solved in [78] which takes into account the data missing phenomenon. In addition, the quantization effect caused by the coding-encoding strategies for NCSs has also been investigated in [79–81].

Compared with the traditionally point-to-point analog feedback control systems, inserting a network to a control loop may cause a series of problems that will deteriorate the system performance or even destabilize the system. Different levels of network- induced imperfections include the following: 1) time delays; 2) packet losses and disorder; 3) time-varying packet transmission/sampling intervals; 4) competition of multiple nodes accessing network; 5) data quantization; 6) clock asynchronization among local and remote nodes; and 7) network security and safety.

During the past decades, extensive studies on network-induced imperfections have been carried out by both the control and the communication communities assuming different scenarios, and various methodologies have been proposed on how to cope with the imperfections. While essentially eliminating the network-induced imperfections cannot be separated from the improvements of the communication infrastructure itself, developing appropriate control theories and approaches in NCSs to overcome these imperfections is of great necessity and significance. Many systematic results in this regard have unfolded with respect to the sources and the modeling of these imperfections and the different approaches for handling them.

Reviews on the advances made in NCSs never cease. Some summaries have been given in different phases, such as the surveys by Tipsuwan and Chow on time-delay problems in NCSs [82], and Hespanha *et al.* on additional types of imperfections in

NCSs [83], such as packet losses, time-varying sampling intervals, and competition of multiple packet transmissions and, more recently Gupta and Chow on other issues of NCSs, such as network security and other realistic considerations [84].

A brief summary of my contributions on this research theme is as follows:

- Due to network traffic congestion and packets transmission failures, packet losses are inevitable in networks especially in a wireless network. An excessively long propagation delay of a packet can be also viewed as a packet lost. Severe consecutive packet losses amount to the disconnection of a network. Therefore, dealing with packet losses in NCSs is a new challenge that is never encountered in point-to-point control systems. How to determine the acceptable lower bound on the packet transmission rate is a major concern in our study.

- In our work, the controlled plant is in continuous time while the controller is in discrete time, which represents a typical computer-based control scheme. The network-induced delays are assumed to have both an upper bound and a lower bound, which is more general than those used in the literature (where the lower bound is assumed to be zero). By using a sampled-data approach, a new model based on the updating instants of the zero-order hold is formulated, and a LMI-based procedure is proposed for designing state-feedback controllers, which guarantee the output of the closed-loop networked control system tracks the output of a given reference model well in H_∞ sense.

- Data quantization is a common phenomenon in all digital control systems, and thus has been a classical topic in conventional digital control theory even before the popularity of NCSs. Quantization means that procedures such as the transformation from analog signals to digital signals, the computer- based realization of a designed controller (e.g., the quantization of some coefficients related to controller gains), and the truncation of words caused by calculations in certain control algorithms. In an NCS, the quantization naturally exists due to the essence of digital control. We regard it as a typical network-induced constraint in our study since it is inseparable from the limited network bandwidth.

- Based on the network feature of transmitting a set of data each time, a predictive control scheme for NCSs with random delays is proposed. In order to compensate for the network delays, an network delay compensator is constructed. Then, the NCSs are formulated as discrete-time Markovian jump systems with discrete and distributed delays. In addition, attention has been given on how to deal with the distributed delays in NCSs. Based on the analysis of the closed-loop systems, the designed predictive time-varying output feedback controller can achieve the desired control performance and can also guarantee the system stability.

Remark: I have published and presented the results of my work widely through a substantial range of top-tier international journals and conference proceedings, such as Automatica, SIAM journals, IEEE Transactions, etc. In particular, my work on hybrid dynamical systems (fuzzy control systems, stochastic jump systems, networked control systems, sampled-data systems) has been widely referred and internationally recognized for its originality and creativity. To recognize my contributions to modeling, analysis, control and filtering on hybrid dynamical systems, I have been elevated to IEEE Fellow, IET Fellow, and IMA Fellow. I have also been invited as editor, subject editor, associate editor and guest editor for a number of prestigious international journals, such as, Automatica, IEEE Trans on Automatic Control, IEEE Trans on Fuzzy Systems; IEEE Trans on Cyberneics; IEEE Trans on Circuits and Systems, Part I: Regular Papers, IEEE Access, Information Sciences; Int. J. of Systems Science; Signal Processing; J. of Intelligent and Fuzzy Systems; Nonlinear Analysis: Real World Applications; Nonlinear Analysis: Hybrid Systems, Journal of the Franklin Institute, and Circuits Systems and Signal Processing. In addition, I have been invited to deliver over 10 Plenary/Keynote

Speeches at international conferences/Workshops.

The above discussion, together with the standard of the publications, has shown that my research has been at the leading edge of four of the major themes of my subject.

3. LIST OF PUBLICATIONS SUBMITTED

The following publications of 3 books and 65 journal papers are selected from the whole body of my published works since 2006. My contribution to each of them varies from 30-80%, ranging from topic selection, writing preparation and structure, problems formulations, proposed techniques, main results development, simulations and proof-reading. All soft and/or hard copies will be provided upon request.

None of these publications contains material that has been accepted for an award of any other degree of diploma in any university or other tertiary institution.

Books

- L. Wu, **P. Shi** and X. Su, *Sliding Mode Control of Uncertain Parameter-Switching Hybrid Systems*, Wiley, London, pp. 1-265, 2014.
- D. Wang, **P. Shi** and W. Wang, *Robust Filtering and Fault Detection of Switched Delay Systems, Springer*, Berlin, pp. 1-148, 2013.
- W. Assawinchaichote, S. K. Nguang and **P. Shi**, *Fuzzy Control and Filtering Design for Uncertain Fuzzy Systems*, Springer, Berlin, pp. 1-176, 2006.

Journal papers

Fuzzy control systems (1-16)

1. F. Li, **P. Shi**, L. Wu and X. Zhang, Fuzzy-model-based-stability and non-fragile control for discrete-time descriptor systems with multiple delays, *IEEE Trans on Fuzzy Systems*, vol. 22, no. 4, pp. 1019-1025, 2014.
2. Z. Wu, **P. Shi**, H. Su and J. Chu, Sampled-data fuzzy control of chaotic systems based on a T-S fuzzy model, *IEEE Trans on Fuzzy Systems*, vol. 22, no. 1, pp. 153-163, 2014.

3. X. Su, **P. Shi**, L. Wu and C. L. Chen, Model approximation for fuzzy switched systems with stochastic perturbation, *IEEE Trans on Fuzzy Systems*, DOI: 10.1109/ TFUZZ.2014. 2362153, Sep 2014.

4. Y. Yin, **P. Shi**, F. Liu, K. L. Teo and C. C. Lim, Robust filtering for nonlinear nonhomogeneous Markov jump systems by fuzzy approximation approach, *IEEE Trans on Cybernetics*, DOI: 10.1109/TCYB.2014.2358680, Aug 2014.

5. X. Su, **P. Shi**, L. Wu and M. Basin, Reliable filtering with strict dissipativity for fuzzy time-delay systems, *IEEE Trans on Cybernetics*, vol. 44, no. 12, pp. 2470-2483, 2014.

6. J. Zhang, **P. Shi**, J. Qiu and S. K. Nguang, A novel observer-based output feedback controller design for discrete-time fuzzy systems, *IEEE Trans on Fuzzy Systems*, vol. 23, no. 1, pp. 223–229, 2015.

7. G. Wang, **P. Shi**, B. Wang and J. Zhang, Fuzzy n-ellipsoid numbers and representations of uncertain multichannel digital information, *IEEE Trans on Fuzzy Systems*, vol. 22, no. 5, pp. 1113-1126, 2014.

8. X. Su, **P. Shi**, L. Wu and Y. Song, A novel control design on discrete-time Takagi-Sugeno fuzzy systems with time-varying delays, *IEEE Trans on Fuzzy Systems*, vol. 21, no. 4, pp. 655-671, 2013.

9. Q. Zhou, **P. Shi**, S. Xu and H. Li, Adaptive output feedback control for nonlinear timedelay systems by fuzzy approximation approach, *IEEE Trans on Fuzzy Systems*, vol. 21, no. 2, pp. 301-313, 2013.

10. J. Wang, **P. Shi**, H. Peng, M. J. Perez-Jimenez and T. Wang, Weighted fuzzy spiking neural P systems, *IEEE Trans on Fuzzy Systems*, vol. 21, no. 2, pp. 209-220, 2013.

11. X. Su, **P. Shi**, L.Wu and Y. Song, A novel approach to filter design for T-S fuzzy discrete-time systems with time-varying delay, *IEEE Trans on Fuzzy Systems*, vol. 20, no. 6, pp. 1114-1129, 2012.

12. Z. Wu, **P. Shi**, H. Su and J. Chu, Reliable H_∞ control for discrete-time fuzzy systems with infinite-distributed delay, *IEEE Trans on Fuzzy Systems*, vol. 20, no. 1, pp. 22-31, 2012.

13. Q. Zhou, **P. Shi**, J. Lu and S. Xu, Adaptive output feedback fuzzy tracking control for a class of nonlinear systems, *IEEE Trans on Fuzzy Systems*, vol. 19, no. 5, pp. 972-982, 2011.

14. J. Zhang, **P. Shi** and Y. Xia, Robust adaptive sliding mode control for fuzzy systems with mismatched uncertainties, *IEEE Trans on Fuzzy Systems*, vol. 18, no. 4, pp. 700-711, 2010.

15. G. Wang, **P. Shi** and P. Messenger, Representation of uncertain multichannel digital signal spaces and study of pattern recognition based on metrics and difference values on fuzzy n-Cell number spaces, *IEEE Trans on Fuzzy Systems*, vol. 17, no. 2, pp. 421-439, 2009.

16. S. K. Nguang, **P. Shi** and S. Ding, Fault detection for uncertain fuzzy systems: an LMI approach, *IEEE Trans on Fuzzy Systems*, vol. 15, no. 6, pp. 1251-1262, 2007.

Neural networks (17-31)

17. **P. Shi**, Y. Zhang and R. Agarwal, Stochastic finite-time state estimation for discrete time-delay neural networks with Markovian jumps, *Neurocomputing*, vol. 151, pp. 168-174, 2015.

18. C. K. Anh, **P. Shi** and L. Wu, Receding horizon stabilization and disturbance attenuation for neural networks with time-varying delay, *IEEE Trans on Cybernetics*, DOI: 10.1109/TCYB.2014.2381604, Dec 2014.

19. Q. Shen, **P. Shi**, T. Zhang and C. C. Lim, Novel neural control for a class of uncertain pure-feedback systems, *IEEE Trans on Neural Networks and Learning Systems*, vol. 25, no. 4, pp. 718-727, 2014.

20. Z. Wu, **P. Shi**, H. Su and J. Chu, Local synchronization of chaotic neural networks with sampled-data and saturating actuators, *IEEE Trans on Cybernetics*, vol. 44, no. 12, pp. 2635-2645, 2014.

21. Z. Wu, **P. Shi**, H. Su and J. Chu, Exponential stabilization for sampled-data neural-network-based control systems, *IEEE Trans on Neural Networks and Learning Systems*, DOI: 0.1109/TNNLS.2014.2306202, Feb 2014.

22. J. Yu, **P. Shi**, B. Chen and C. Lin, Neural network-based adaptive dynamic surface control for permanent magnet synchronous motors, *IEEE Trans on Neural Networks and Learning Systems*, vol. 26, no. 3, pp. 640–645, 2015.

23. L. Zhang, Y. Zhu and **P. Shi**, Resilient asynchronous H_∞ filtering for Markov jump neural networks with unideal measurements and multiplicative noises, *IEEE Trans on Cybernetics*, DOI: 10.1109/TCYB.2014.2387203, Dec 2014.

24. Z. Wu, **P. Shi**, H. Su and J. Chu, Stochastic synchronization of Markovian jump neural networks with time-varying delay using sampled-data, *IEEE Trans on Cybernetics*, vol. 43, no. 6, pp. 1796-1806, 2013.

25. Z. Wu, **P. Shi**, H. Su and J. Chu, Dissipativity analysis for discrete-time stochastic neural networks with time-varying delays, *IEEE Trans on Neural Networks and Learning Systems*, vol. 24, no. 3, pp. 345-355, 2013.

26. Q. Zhou, **P. Shi**, S. Xu and H. Li, Observer-based adaptive neural network control for nonlinear stochastic systems with time-delay, *IEEE Trans on Neural Networks and Learning Systems*, vol. 24, no. 1, pp. 71-80, 2013.

27. Z. Wu, **P. Shi**, H. Su and J. Chu, Sampled-data synchronization of chaotic Lur'e systems with time delays, *IEEE Trans on Neural Networks and Learning Systems*, vol. 24, no. 3, pp. 410-421, 2013.

28. Q. Zhou, **P. Shi**, H. Liu and S. Xu, Neural-network-based decentralized adaptive outputfeedback control for large-scale stochastic nonlinear systems, *IEEE Trans on Systems, Man and Cybernetics, Part B: Cybernetics*, vol. 42, no. 6, pp. 1608-1619, 2012.

29. Z. Wu, **P. Shi**, H. Su and J. Chu, Exponential synchronization of neural networks with discrete and distributed delays under time-varying sampling, *IEEE Trans on Neural Networks and Learning Systems*, vol. 23, no. 9, pp. 1368-1376, 2012.

30. Z. Wu, **P. Shi**, H. Su and J. Chu, Delay-dependent stability analysis for switched neural networks with time-varying delay, *IEEE Trans on Systems, Man and Cybernetics, Part B: Cybernetics*, vol. 41, no. 6, pp. 1522-1530, 2011.

31. Z. Wu, **P. Shi**, H. Su and J. Chu, Passivity analysis for discrete-time stochastic Markovian jump neural networks with mixed time-delays, *IEEE Trans on Neural Networks*, vol. 22, no. 10, pp. 1566-1575, 2011.

Stochastic systems (32-50)

32. Z. Wu, **P. Shi**, H. Su and J. Chu, Asynchronous l_2-l_∞ filtering for discrete-time stochastic Markov jump systems with randomly occurred sensor nonlinearities, *Automatica*, vol. 1, no. 1, pp. 180-186, 2014.

33. **P. Shi**, Y. Yin, F. Liu and J. Zhang, Robust control on saturated Markov jump systems with missing information, *Information Sciences*, vol. 265, pp. 123-138, 2014.

34. Y. Wang, **P. Shi**, Q. Wang and D. Duan, Exponential H_∞ filtering for singular Markovian jump systems with mixed mode-dependent time-varying delay, *IEEE Trans on Circuits and Systems-I*, vol. 60, no. 9, pp. 2440-2452, 2013.

35. M. Liu and **P. Shi**, Sensor fault estimation and tolerant control for Itô stochastic systems with simultaneous input and output disturbances, *Automatica*, vol. 49, no. 5, pp. 1242-1250, 2013.

36. J. Lian, **P. Shi** and Z. Feng, Passivity and passification for a class of uncertain switched stochastic time-delay systems, *IEEE Trans on Cybernetics*, vol. 43, no. 1, pp. 3-13, 2013.

37. **P. Shi**, Y. Yin and F. Liu, Gain-scheduled worst case control on nonlinear stochastic systems subject to actuator saturation and unknown information, *J. of Optimization Theory and Applications*, vol. 156, no. 3, pp. 844-858, 2013.

38. **P. Shi**, X. Luan and F. Liu, H_∞ filtering for discrete-time systems with stochastic incomplete measurement and mixed delays, *IEEE Trans on Industrial Electronics*, vol. 59, no. 6, pp. 2732-2739, 2012.

39. Z. Wu, M. Cui and **P. Shi**, Backstepping control in vector form for stochastic Hamiltonian systems, *SIAM Journal on Control and Optimization*, vol. 50, no. 2, pp. 925-942, 2012.

40. V. Dragan, H. Mukaidani and **P. Shi**, The linear quadratic regulator problem for a class of controlled systems modeled by singularly perturbed Itô differential equations, *SIAM J. on Control and Optimization*, vol. 50, no. 1, pp. 448-470, 2012.

41. Y. Yin, **P. Shi** and F. Liu, Gain-scheduled robust fault detection on time-delay stochastic nonlinear systems, *IEEE Trans on Industrial Electronics*, vol. 58, no. 10, pp. 4908-4916, 2011.

42. **P. Shi** and M. Liu, Discussion On the filtering problem for continuous-time Markov jump linear systems with no observation of the Markov chain, *European J. of Control*, vol. 17, no. 4, pp. 355-356, 2011.

43. M. Liu, **P. Shi**, L. Zhang and X. Zhao, Fault tolerant control for nonlinear Markovian jump systems via proportional and derivative sliding mode observer, *IEEE Trans on Circuits and Systems I: Regular Papers*, vol. 58, no. 11, pp. 2755-2764, 2011.

44. L. Wu, **P. Shi** and H. Gao, State estimation and sliding mode control of Markovian jump singular systems, *IEEE Trans on Automatic Control*, vol. 55, no. 5, pp. 1213-1219, 2010.

45. L. Zhang and **P. Shi**, Stability, l_2-gain and asynchronous H_∞ control of discrete-time switched systems with average dwell time, *IEEE Trans on Automatic Control*, vol. 54, no. 9, pp. 2193-2200, 2009.

46. L. Hu, **P. Shi** and P. Frank, Robust sampled-data control for Markovian jump linear systems, *Automatica*, vol. 42, pp. 2025-2030, 2006.

47. M. Karan, **P. Shi** and Y. Kaya, Transition probability bounds for the stochastic stability robustness of continuous- and discrete-time Markovian jump linear systems, *Automatica*, vol. 42, pp. 2159-2168, 2006.

48. **P. Shi**, Y. Xia, G. Liu and D. Rees, On designing of sliding mode control for stochastic jump systems, *IEEE Trans on Automatic Control*, vol. 51, no. 1, pp. 97-103, 2006.

49. **P. Shi**, M. Mahmoud, S. Nguang and A. Ismail, Robust filtering for jumping systems with mode-dependent delays, *Signal Processing*, vol. 86, pp. 140-152, 2006.

50. **P. Shi**, M. Mahmoud, J. Yi and A. Ismail, Worst case control of uncertain jumping systems with multi-state and input delay information, *Information Sciences*, vol. 176, no. 2, pp. 186-200, 2006.

Networked control systems (51-65)

51. **P. Shi** and Q. Shen, Cooperative control of multi-agent systems with unknown state-dependent controlling effects, *IEEE Trans on Automation Science and Engineering*, accepted, Jan 2015.

52. H. Wang, **P. Shi** and J. Zhang, Event-triggered fuzzy filtering for a class of nonlinear networked control systems, *Signal Processing*, vol. 113, pp. 159–168, 2015.

53. C. Ma, **P. Shi**, X. Zhao and Q. Zeng, Consensus of Euler-Lagrange systems networked by sampled-data information with probabilistic time delays, *IEEE Trans on Cybernetics*, DOI: 10.1109/TCYB.2014.2345735, Jul 2014.

54. F. Li, **P. Shi**, L. Wu, C. C. Lim and M. Basin, Quantized control design for cognitive radio networks modeled as nonlinear semi-Markovian jump systems, *IEEE Trans on Industrial Electronics*, vol. 62, no. 4, pp. 2330–2340, 2015.

55. R. Yang, **P. Shi** and G. Liu, Filtering for discrete-time networked nonlinear systems with mixed random delays and packet dropouts, *IEEE Trans on Automatic Control*, vol. 56, no. 11, pp. 2655-2660, 2011.

56. R. Yang, **P. Shi**, G. Liu and H. Gao, Network-based feedback control for systems

with mixed delays based on quantization and dropout compensation, *Automatica*, vol. 47, no. 12, pp. 2805-2809, 2011.

57. X. Luan, **P. Shi** and F. Liu, Stabilization of networked control systems with random delays, *IEEE Trans on Industrial Electronics*, vol. 58, no. 9, pp. 4323-4330, 2011.

58. R. Yang, G. Liu, **P. Shi**, C. Thomas and M. Basin, Predictive output feedback control for networked control systems, *IEEE Trans on Industrial Electronics*, vol. 61, no. 1, pp. 512-520, 2014.

59. X. Su, **P. Shi**, L. Wu and S. Nguang, Induced l_2 filtering of fuzzy stochastic systems with time-varying delays, *IEEE Trans on Cybernetics*, vol. 43, no. 4, pp. 1251-1264, 2013.

60. Z. Wu, **P. Shi**, H. Su and J. Chu, Sampled-data exponential synchronization of complex dynamical networks with time-varying coupling delay, *IEEE Trans on Neural Networks and Learning Systems*, vol, 24, no. 8, pp. 1177-1187, 2013.

61. J. Zhang, **P. Shi** and Y. Xia, Fuzzy delay compensation control for T-S fuzzy systems over network, *IEEE Trans on Cybernetics*, vol. 43, no. 1, pp. 259-268, 2013.

62. Z. Wu, **P. Shi**, H. Su and J. Chu, Network-based robust passive control for fuzzy systems with randomly occurring uncertainties, *IEEE Trans on Fuzzy Systems*, vol. 21, no. 5, pp. 966-971, 2013.

63. J. Zhang, Y. Xia and **P. Shi**, Design and stability analysis of networked predictive control systems, *IEEE Trans on Control Systems Technology*, vol. 21, no. 4, pp. 1495-1501, 2013.

64. H. Yang, Y. Xia, **P. Shi** and M. Fu, Stability analysis for high frequency networked control systems, *IEEE Trans on Automatic Control*, vol. 57, no. 10, pp. 2694-2700, 2012.

65. X. Su, L. Wu and **P. Shi**, Senor networks with random link failures: distributed filtering for T-S fuzzy systems, *IEEE Trans on Industrial Informatics*, vol. 9, no. 3, pp. 1739-1750, 2013.

Publication Description

1. L. Wu, **P. Shi** and X. Su, *Sliding Mode Control of Uncertain Parameter-Switching Hybrid Systems*, Wiley, London, pp. 1-265, 2014.

   This book addresses the increasing demand for developing sliding mode control (SMC) technologies and comprehensively presents the new, state-of-the-art sliding mode control methodologies for uncertain parameter-switching hybrid systems. A series of problems are solved with new approaches for analysis and synthesis of switched hybrid systems, including stability analysis and stabilization, dynamic output feedback control, and SMC. Some newly developed techniques (e.g. average dwell time, piecewise Lyapunov function, parameter-dependent Lyapunov function, cone complementary linearization) are exploited to handle the emerging mathematical/computational challenges.

2. D. Wang, **P. Shi** and W. Wang, *Robust Filtering and Fault Detection of Switched Delay Systems*, Springer, Berlin, pp. 1-148, 2013.

   This book studies the problems of filter design and fault detection of switched delay systems including two parts. In the first part, the problem of filter design for switched systems with state delays is investigated under different switching signals. In the second part, the problems of robust fault detection for switched systems with state delays under an arbitrary switching signal and a switching signal with average dwell time are studied. The fault detection filter is employed as the residual generator and designed to minimize the estimation error between the residuals and faults.

3. W. Assawinchaichote, S. K. Nguang and **P. Shi**, *Fuzzy Control and Filtering Design for Uncertain Fuzzy Systems*, Springer, Berlin, pp. 1-176, 2006.

This book presents new novel methodologies for designing robust H_∞ fuzzy controllers and robust H_∞ fuzzy filters for a class of uncertain fuzzy systems, uncertain fuzzy Markovian jump systems, uncertain fuzzy singularly perturbed systems and uncertain fuzzy singularly perturbed systems with Markovian jumps. These new methodologies provide a framework for designing robust H_∞ fuzzy controllers and robust H_∞ fuzzy filters for these classes of systems based on a Tagaki-Sugeno fuzzy model.

4. F. Li, **P. Shi**, L. Wu and X. Zhang, Fuzzy-model-based-stability and non-fragile control for discrete-time descriptor systems with multiple delays, *IEEE Trans on Fuzzy Systems*, vol. 22, no. 4, pp. 1019-1025, 2014.

   This paper is concerned with the problems of D-stability and nonfragile control for a class of discrete-time descriptor Takagi-Sugeno (T-S) fuzzy systems with multiple state delays. D-stability criteria are proposed to ensure that all the poles of the descriptor T-S fuzzy system are located within a disk contained in the unit circle. Furthermore, a sufficient condition is presented such that the closed-loop system is regular, causal, and D-stable, in spite of parameter uncertainties and multiple state delays. The corresponding solvability conditions for the desired fuzzy-rule dependent nonfragile controllers are also established.

5. Z. Wu, **P. Shi**, H. Su and J. Chu, Sampled-data fuzzy control of chaotic systems based on a T-S fuzzy model, *IEEE Trans on Fuzzy Systems*, vol. 22, no. 1, pp. 153-163, 2014.

   In this paper, a sampled-data fuzzy controller is designed to stabilize a class of chaotic systems based on a Takagi-Sugeno fuzzy model. The exponential stability issue of the closed-loop systems with an input constraint is first investigated by a novel time-dependent Lyapunov functional, which is positive definite at sampling times. Then, two sufficient conditions are developed for sampled-data fuzzy *controller synthesis of the underlying T-S fuzzy model with or without input constraint. All the proposed results depend on both the upper and lower bounds on a sampling interval, and the available information about the actual sampling pattern is fully utilized.*

6. X. Su, **P. Shi**, L. Wu and C. L. Chen, Model approximation for fuzzy switched systems with stochastic perturbation, *IEEE Trans on Fuzzy Systems*, DOI: 10.1109/ TFUZZ.2014.2362153, Sep 2014.

   The model approximation problem is investigated for T-S fuzzy switched system with stochastic disturbance in this paper. For a high-order considered system, our attention is focused on the construction of a reduced-order model, which not only approximates the original system well with a Hankel-norm performance but also translates it into a lower-dimensional fuzzy switched system. By using the average dwell time approach and the piecewise Lyapunov function technique, a sufficient condition is proposed to guarantee the mean-square exponential stability with a Hankel-norm error performance for the error system.

7. 4. Y. Yin, **P. Shi**, F. Liu, K. L. Teo and C. C. Lim, Robust filtering for nonlinear nonhomogeneous Markov jump systems by fuzzy approximation approach, *IEEE Trans on Cybernetics*, DOI: 10.1109/TCYB.2014.2358680, Aug 2014.

   This paper addresses the problem of robust fuzzy (L_2-L_∞) filtering for a class of uncertain nonlinear discrete-time Markov jump systems (MJSs) with nonhomogeneous jump processes. The Takagi-Sugeno fuzzy model is employed to represent such nonlinear nonhomogeneous MJS with norm-bounded parameter uncertainties. In order to decrease conservation, a polytope Lyapunov function which evolves as a convex function is employed, and then, under the designed mode-dependent and variation-dependent fuzzy filter which includes the membership functions, a sufficient condition is presented to ensure that the filtering error *dynamic system is stochastically stable and that it has a prescribed (L_2-L_∞) performance index.*

8. X. Su, **P. Shi**, L. Wu and M. Basin, Reliable filtering with strict dissipativity for fuzzy time-delay systems, *IEEE Trans on Cybernetics*, vol. 44, no. 12, pp. 2470-2483, 2014.

   In this paper, the problem of reliable filter design with strict dissipativity has been investigated for a class of discrete-time T-S fuzzy time-delay systems. Our attention is focused on the design of a reliable filter to ensure a strictly dissipative performance for the filtering error system. Based on the reciprocally convex approach, firstly, a sufficient condition of reliable dissipativity analysis is proposed for T-S fuzzy systems with time-varying delays and sensor failures. Then, a reliable filter with strict dissipativity is designed by solving a convex optimization problem, which can be efficiently solved by standard numerical algorithms.

9. J. Zhang, **P. Shi**, J. Qiu and S. K. Nguang, A novel observer-based output feedback controller design for discrete-time fuzzy systems, *IEEE Trans on Fuzzy Systems*, vol. 23, no. 1, pp. 223-229, Feb. 2015.

   This paper addresses the problem of observer-based output feedback controller designs for discrete-time T-S fuzzy systems based on a relaxed approach in which the fuzzy Lyapunov functions are used. Different from the existing two-step method, a single-step linear matrix inequality method is provided for the observer-based controller design. It is shown that the controller and observer parameters can be obtained by solving a set of strict linear matrix inequalities that are numerically feasible with commercially available software. The design method not only overcomes the drawback induced by the two-step approach but also provides less conservative results over some existing results.

10. G. Wang, **P. Shi**, B. Wang and J. Zhang, Fuzzy n-ellipsoid numbers and representations of uncertain multichannel digital information, *IEEE Trans on Fuzzy Systems*, vol. 22, no. 5, pp. 1113-1126, 2014.

    This paper investigates the definition of fuzzy n-ellipsoid numbers that are a special kind n-dimensional fuzzy numbers which are not only more objective and more rational in expressing uncertain multichannel digital information than fuzzy n-cell numbers but also convenience when being used in applications and researches. Then, we define some special kinds of fuzzy n-ellipsoid numbers, investigate their properties, set up a specific iterative algorithm, and prove the convergence of the iterative algorithm. And then, we establish an algorithmic version of constructing fuzzy n-ellipsoid numbers to express an object that is characterized by a group of uncertain multichannel digital information.

11. X. Su, **P. Shi**, L. Wu and Y. Song, A novel control design on discrete-time Takagi-Sugeno fuzzy systems with time-varying delays, *IEEE Trans on Fuzzy Systems*, vol. 21, no. 4, pp. 655-671, 2013.

    This paper focuses on analyzing a new model transformation of discrete-time Takagi-Sugeno (T-S) fuzzy systems with time-varying delays and applying it to dynamic output feedback (DOF) controller design. A sufficient condition on discrete-time T-S fuzzy systems with time-varying delays, which guarantees the corresponding closed-loop system to be asymptotically stable and has an induced l(2) disturbance attenuation performance, is derived by employing the scaled small-gain theorem. Then, the solvability condition for the induced l(2) DOF control is also established, by which the DOF controller can be solved as linear matrix inequality optimization problems.

12. Q. Zhou, **P. Shi**, S. Xu and H. Li, Adaptive output feedback control for nonlinear time delay systems by fuzzy approximation approach, *IEEE Trans on Fuzzy*

Systems, vol. 21, no. 2, pp. 301-313, 2013.

This paper investigates the problem of adaptive fuzzy tracking control via output feedback for uncertain single-input single-output strict-feedback nonlinear systems with unknown time-delay functions. Dynamic surface control technique is used to avoid the problem of "explosion of complexity", which is caused by repeated differentiation of certain nonlinear functions in the backstepping design process. In addition, the fuzzy logic systems are utilized to approximate the unknown and desired control input signals. The designed controller can guarantee all the signals in the closed-loop system to be semiglobally uniformly bounded and the tracking error to converge to a small neighborhood of the origin.

13. J. Wang, **P. Shi**, H. Peng, M. J. Perez-Jimenez and T. Wang, Weighted fuzzy spiking neural P systems, *IEEE Trans on Fuzzy Systems*, vol. 21, no. 2, pp. 209-220, 2013.

    Spiking neural P (SNP) systems are a new class of computing models inspired by the neurophysiological behavior of biological spiking neurons. A new class of SNP systems is proposed called weighted fuzzy SNP systems to adequately characterize the features of weighted fuzzy production rules. Furthermore, a weighted fuzzy backward reasoning algorithm is developed, which can accomplish dynamic fuzzy reasoning of a rule-based system more flexibly and intelligently. In addition, we compare the proposed weighted fuzzy SNP systems with other knowledge representation methods, such as fuzzy production rule and conceptual graph, to demonstrate the features and advantages of the proposed techniques.

14. X. Su, **P. Shi**, L. Wu and Y. Song, A novel approach to filter design for T-S fuzzy discrete-time systems with time-varying delay, *IEEE Trans on Fuzzy Systems*, vol. 20, no. 6, pp. 1114-1129, 2012.

In this paper, the problem of l_2*-*l_∞ *filtering for a class of discrete-time Takagi-Sugeno (T-S) fuzzy time-varying delay systems is studied. Our attention is focused on the design of full-and reduced-order filters that guarantee the filtering error system to be asymptotically stable with a prescribed* H_∞ *performance. Sufficient conditions for the obtained filtering error system are proposed by applying an input-output approach and a two-term approximation method, which is employed to approximate the time-varying delay. The corresponding full-and reduced-order filter design is cast into a convex optimization problem, which can be efficiently solved by standard numerical algorithms.*

15. Z. Wu, **P. Shi**, H. Su and J. Chu, Reliable H_∞ control for discrete-time fuzzy systems with infinite-distributed delay, *IEEE Trans on Fuzzy Systems*, vol. 20, no. 1, pp. 22-31, 2012.

    In this paper, the problem of reliable H_∞ *control is investigated for discrete-time Takagi-Sugeno (T-S) fuzzy systems with infinite-distributed delay and actuator faults. A discrete-time homogeneous Markov chain is used to represent the stochastic behavior of actuator faults. In terms of a stochastic fuzzy Lyapunov functional, a sufficient condition is proposed to ensure that the resultant closed-loop system is exponentially stable in the meansquare sense with an* H_∞ *performance index. Based on the derived condition, the reliable* H_∞ *control problem is solved, and an explicit expression of the desired controller is also given.*

16. Q. Zhou, **P. Shi**, J. Lu and S. Xu, Adaptive output feedback fuzzy tracking control for a class of nonlinear systems, *IEEE Trans on Fuzzy Systems*, vol. 19, no. 5, pp. 972–982, 2011.

    This paper is concerned with the problem of adaptive fuzzy tracking control via output feedback for a class of uncertain single-input single-output (SISO) strict-feedback nonlinear systems. The dynamic feedback strategy begins with an input-

driven filter. By utilizing fuzzy logic systems to approximate unknown and desired control input signals directly instead of the unknown nonlinear functions, an output-feedback fuzzy tracking controller is designed via a backstepping approach. It is shown that the proposed fuzzy adaptive output controller can guarantee that all the signals remain bounded and that the tracking error converges to a small neighborhood of the origin.

17. J. Zhang, **P. Shi** and Y. Xia, Robust adaptive sliding mode control for fuzzy systems with mismatched uncertainties, *IEEE Trans on Fuzzy Systems*, vol. 18, no. 4, pp. 700-711, 2010.

    This paper is devoted to design adaptive sliding-mode controllers for the Takagi-Sugeno (T-S) fuzzy system with mismatched uncertainties and exogenous disturbances. The uncertainties in state matrices are mismatched and norm-bounded, while the exogenous disturbances are assumed to be bounded with an unknown bound, which is estimated by a simple and effective adaptive approach. Both state-and static-output-feedback sliding-mode-control problems are considered. In terms of linear-matrix inequalities (LMIs), both sliding surfaces and sliding-mode controllers can be easily obtained via a convex optimization technique.

18. G. Wang, **P. Shi** and P. Messenger, Representation of uncertain multichannel digital signal spaces and study of pattern recognition based on metrics and difference values on fuzzy n-Cell number spaces, *IEEE Trans on Fuzzy Systems*, vol. 17, no. 2, pp. 421–439, 2009.

    This paper studies the problem of characterization for uncertain multichannel digital signal spaces, propose using fuzzy n-cell number space to represent uncertain n-channel digital signal space, and put forward a method of constructing such fuzzy n-cell numbers. We introduce two new metrics and concepts of certain types of difference values on fuzzy n-cell number space and study their properties.

Further, based on the metrics or difference values appropriately defined, we put forward an algorithmic version of pattern recognition in an imprecise or uncertain environment, and we also give practical examples to show the application and rationality of the proposed techniques.

19. S. K. Nguang, **P. Shi** and S. Ding, Fault detection for uncertain fuzzy systems: an LMI approach, *IEEE Trans on Fuzzy Systems*, vol. 15, no. 6, pp. 1251–1262, 2007.

    This paper studies the problem of designing a robust fault-detection system for uncertain Takagi-Sugeno fuzzy models. The worst case fault sensitivity measure is formulated in terms of linear matrix inequalities. The existence of a robust fault detection system that guarantees i) the L(2)-gain from a fault signal to a residual signal greater than a prescribed value and ii) the L_2-gain from an exogenous input to a residual signal less than a prescribed value is given in terms of the solvability of linear matrix inequalities. Numerical examples are used to illustrate the effectiveness of the proposed design techniques.

20. **P. Shi**, Y. Zhang and R. Agarwal, Stochastic finite-time state estimation for discrete time-delay neural networks with Markovian jumps, *Neurocomputing*, vol. 151, pp. 168–174, 2015.

    This paper investigates the problem of stochastic finite-time state estimation for a class of uncertain discrete-time Markovian jump neural networks with time-varying delays. A state estimator is designed to estimate the network states through available output measurements such that the resulted error dynamics is stochastically finite-time stable. By stochastic Lyapunov-Krasovskii functional approach, sufficient conditions are derived for the error dynamics to be stochastic finite-time stable. The desired state estimator is designed via linear matrix inequality technique. Simulation examples are provided to illustrate the effectiveness *of the obtained results.*

21. C. K. Anh, **P. Shi** and L. Wu, Receding horizon stabilization and disturbance attenuation for neural networks with time-varying delay, *IEEE Trans on Cybernetics*, DOI: 10.1109/TCYB.2014.2381604, Dec 2014.

    This paper is concerned with the problems of receding horizon stabilization and disturbance attenuation for neural networks with time-varying delay. New delay-dependent conditions on the terminal weighting matrices of a new finite horizon cost functional for receding horizon stabilization are established for neural networks with time-varying or time-invariant delays using single- and double-integral Wirtinger-type inequalities. Based on the results, delay-dependent sufficient conditions for the receding horizon disturbance attenuation are given to guarantee the infinite horizon H_∞ performance of neural networks with time-varying or time-invariant delays. Three numerical examples are provided to illustrate the effectiveness of the proposed approach.

22. Q. Shen, **P. Shi**, T. Zhang and C. C. Lim, Novel neural control for a class of uncertain pure-feedback systems, *IEEE Trans on Neural Networks and Learning Systems*, vol. 25, no. 4, pp. 718–727, 2014.

    This paper investigates the problem of adaptive neural tracking control for a class of uncertain pure-feedback nonlinear systems. Using the implicit function theorem and back-stepping technique, a practical robust adaptive neural control scheme is proposed to guarantee that the tracking error converges to an adjusted neighborhood of the origin. An alternative Lyapunov function is constructed for the development of control law and learning algorithms. Furthermore, the scheme requires the desired trajectory and its first derivative. In addition, the useful property of the basis function of the radial basis function, which will be used in control design, is explored.

23. Z. Wu, **P. Shi**, H. Su and J. Chu, Local synchronization of chaotic neural networks with sampled-data and saturating actuators, *IEEE Trans on Cybernetics*, vol. 44, no. 12, pp. 2635–2645, 2014.

    This paper investigates the problem of local synchronization of chaotic neural networks with sampled-data and actuator saturation. A new time-dependent Lyapunov functional is proposed for the synchronization error systems. A local stability condition of the synchronization error systems is derived, based on which a sampled-data controller with respect to the actuator saturation is designed to ensure that the master neural networks and slave neural networks are locally asymptotically synchronous. Two optimization problems are provided to compute the desired sampled-data controller with the aim of enlarging the set of admissible initial conditions or the admissible sampling upper bound.

24. Z. Wu, **P. Shi**, H. Su and J. Chu, Exponential stabilization for sampled-data neural-network-based control systems, *IEEE Trans on Neural Networks and Learning Systems*, vol. 25, no. 12, pp. 2180–2190, 2014.

    This paper investigates the problem of sampled-data stabilization for neural-network-based control systems with an optimal guaranteed cost. Using time-dependent Lyapunov functional approach, some novel conditions are proposed to guarantee the closed-loop systems exponentially stable, which fully use the available information about the actual sampling pattern. Based on the derived conditions, the design methods of the desired sampled-data three-layer fully connected feedforward neural-network-based controller are established to obtain the largest sampling interval and the smallest upper bound of the cost function. A practical example is provided to demonstrate the effectiveness and feasibility of the proposed techniques.

25. J. Yu, **P. Shi**, B. Chen and C. Lin, Neural network-based adaptive dynamic

surface control for permanent magnet synchronous motors, *IEEE Trans on Neural Networks and Learning Systems*, vol. 26, no. 3, pp. 640–645, 2015.

This brief considers the problem of neural networks (NNs)-based adaptive dynamic surface control (DSC) for permanent magnet synchronous motors. First, NNs are used to approximate the unknown and nonlinear functions of PMSM drive system and a novel adaptive DSC is constructed to avoid the explosion of complexity in the backstepping design. Next, under the proposed adaptive neural DSC, the number of adaptive parameters required is reduced to only one, and the designed neural controller structure is much simpler than some existing results in literature, which can guarantee that the tracking error converges to a small neighborhood of the origin.

26. L. Zhang, Y. Zhu and **P. Shi**, Resilient asynchronous H_∞ filtering for Markov jump neural networks with unideal measurements and multiplicative noises, *IEEE Trans on Cybernetics*, DOI: 10.1109/TCYB.2014.2387203, Dec 2014.

    This paper is concerned with the resilient H_∞ filtering problem for a class of discrete-time Markov jump neural networks (NNs) with time-varying delays, unideal measurements, and multiplicative noises. The transitions of NNs modes and desired mode-dependent filters are considered to be asynchronous, and a nonhomogeneous mode transition matrix of filters is used to model the asynchronous jumps to different degrees that are also mode-dependent. The desired resilient filters are designed such that the filtering error system is stochastically stable with a guaranteed H_∞ performance index. A monotonicity is disclosed in filtering performance index as the degree of asynchronous jumps changes.

27. Z. Wu, **P. Shi**, H. Su and J. Chu, Stochastic synchronization of Markovian jump neural networks with time-varying delay using sampled-data, *IEEE Trans on Cybernetics*, vol. 43, no. 6, pp. 1796-1806, 2013.

In this paper, the problem of sampled-data synchronization for Markovian jump neural networks with time-varying delay and variable samplings is considered. In the framework of the input delay approach and the linear matrix inequality technique, two delay-dependent criteria are derived to ensure the stochastic stability of the error systems, and thus, the master systems stochastically synchronize with the slave systems. The desired mode-independent controller is designed, which depends upon the maximum sampling interval. The effectiveness and potential of the obtained results is verified by two simulation examples.

28. Z. Wu, **P. Shi**, H. Su and J. Chu, Dissipativity analysis for discrete-time stochastic neural networks with time-varying delays, *IEEE Trans on Neural Networks and Learning Systems*, vol. 24, no. 3, pp. 345-355, 2013.

    In this paper, the problem of dissipativity analysis is discussed for discrete-time stochastic neural networks with time-varying discrete and finite-distributed delays. The discretized Jensen inequality and lower bounds lemma are adopted to deal with the involved finite sum quadratic terms, and a sufficient condition is derived to ensure the considered neural networks to be globally asymptotically stable in the mean square and strictly (Q, S, R)-gamma-dissipative, which is delay-dependent in the sense that it depends on not only the discrete delay but also the finite-distributed delay. Based on the dissipativity criterion, some special cases are also discussed.

29. Q. Zhou, **P. Shi**, S. Xu and H. Li, Observer-based adaptive neural network control for nonlinear stochastic systems with time-delay, *IEEE Trans on Neural Networks and Learning Systems*, vol. 24, no. 1, pp. 71-80, 2013.

    This paper considers the problem of observer-based adaptive neural network (NN) control for a class of single-input single-output strict-feedback nonlinear stochastic systems with unknown time delays. Dynamic surface control is used to avoid the *so-called explosion of complexity in the backstepping design process. Radial basis function NNs are directly utilized to approximate the unknown and desired control input signals instead of the unknown nonlinear functions. The proposed adaptive NN output feedback controller can guarantee all the signals in the closed-loop system to be mean square semi-globally uniformly ultimately bounded.*

30. Z.Wu, **P. Shi**, H. Su and J. Chu, Sampled-data synchronization of chaotic Lur'e systems with time delays, *IEEE Trans on Neural Networks and Learning Systems*, vol. 24, no. 3, pp. 410-421, 2013.

    This paper studies the problem of sampled-data control for master-slave synchronization schemes that consist of chaotic Lur'e systems with time delays. It is assumed that the sampling periods are arbitrarily varying but bounded. In order to take full advantage of the available information about the actual sampling pattern, a novel Lyapunov functional is proposed, which is positive definite at sampling times but not necessarily positive definite inside the sampling intervals. Based on the Lyapunov functional, an exponential synchronization criterion is derived by analyzing the corresponding synchronization error systems. The desired sampled-data controller is designed by a linear matrix inequality approach.

31. Q. Zhou, **P. Shi**, H. Liu and S. Xu, Neural-network-based decentralized adaptive output feedback control for large-scale stochastic nonlinear systems, *IEEE Trans on Systems, Man and Cybernetics, Part B: Cybernetics*, vol. 42, no. 6, pp. 1608-1619, 2012.

    This paper focuses on the problem of neural-network-based decentralized adaptive output-feedback control for a class of nonlinear strict-feedback large-scale stochastic systems. The dynamic surface control technique is used to avoid the explosion of computational complexity in the backstepping design process. A novel direct adaptive neural network approximation method is proposed to approximate *the unknown and desired control input signals instead of the unknown nonlinear functions. It is shown that the designed controller can guarantee all the signals in the closed-loop system to be semiglobally uniformly ultimately bounded in a mean square.*

32. Z. Wu, **P. Shi**, H. Su and J. Chu, Exponential synchronization of neural networks with discrete and distributed delays under time-varying sampling, *IEEE Trans on Neural Networks and Learning Systems*, vol. 23, no. 9, pp. 1368-1376, 2012.

    This paper investigates the problem of master-slave synchronization for neural networks with discrete and distributed delays under variable sampling. An improved method is proposed, which captures the characteristic of sampled-data systems. Some delay-dependent criteria are derived to ensure the exponential stability of the error systems, and thus the master systems synchronize with the slave systems. The desired sampled-data controller can be achieved by solving a set of linear matrix inequalities, which depend upon the maximum sampling interval and the decay rate. The obtained conditions not only have less conservatism but also have less decision variables than existing results.

33. Z. Wu, **P. Shi**, H. Su and J. Chu, Delay-dependent stability analysis for switched neural networks with time-varying delay, *IEEE Trans on Systems, Man and Cybernetics, Part B: Cybernetics*, vol. 41, no. 6, pp. 1522-1530, 2011.

    In this paper, the problem of stability analysis is investigated for switched neural networks with time-varying delay using linear matrix inequality (LMI) approach. By taking advantage of the average dwell time method, two sufficient conditions are developed to ensure the global exponential stability of the considered neural networks, which are delay-dependent and formulated by LMIs. The state decay estimate is explicitly given. Numerical examples are provided to demonstrate the effectiveness and feasibility of the proposed techniques.

34. Z. Wu, **P. Shi**, H. Su and J. Chu, Passivity analysis for discrete-time stochastic Markovian jump neural networks with mixed time-delays, *IEEE Trans on Neural Networks*, vol. 22, no. 10, pp. 1566-1575, 2011.

    In this paper, passivity analysis is conducted for discrete-time stochastic neural networks with both Markovian jumping parameters and mixed time delays. The mixed time delays consist of both discrete and distributed delays. The Markov chain in the underlying neural networks is finite piecewise homogeneous. By introducing a Lyapunov functional that accounts for the mixed time delays, a delay-dependent passivity condition is derived in terms of the linear matrix inequality approach. The case of Markov chain with partially unknown transition probabilities is also considered. All the results presented depend upon not only discrete delay but also distributed delay.

35. Z. Wu, **P. Shi**, H. Su and J. Chu, Asynchronous l_2-l_∞ filtering for discrete-time stochastic Markov jump systems with randomly occurred sensor nonlinearities, *Automatica*, vol. 1, no. 1, pp. 180-186, 2014.

    This paper is concerned with the problem of asynchronous l_2-l_∞ filtering for discrete-time stochastic Markov jump systems with sensor nonlinearity that is assumed to occur randomly according to a stochastic variable satisfying the Bernoulli distribution. A sufficient condition is first given such that the resultant filtering error system is stochastically stable with a guaranteed l_2-l_∞ performance index. Then the existence criterion of the desired asynchronous filter with piecewise homogeneous Markov chain is proposed. A numerical example is given to show the effectiveness and potential of the developed theoretical results.

36. **P. Shi**, Y. Yin, F. Liu and J. Zhang, Robust control on saturated Markov jump systems with missing information, *Information Sciences*, vol. 265, pp. 123-138, 2014.

In this paper, a robust H_∞ controller is designed for saturated Markov jump systems with uncertainties and time varying transition probabilities. The time-varying transition probability uncertainty is described as a polytope set. Stochastic stability is analyzed for the underlying systems by Lyapunov function approach and a sufficient condition is derived to design controllers such that the resulting closed-loop system is stochastically stable and achieving a prescribed H_∞ performance. Furthermore, the attraction domain of this Markov jump system is estimated and evaluated. A simulation example is given to show the effectiveness of the developed techniques.

37. Y. Wang, **P. Shi**, Q. Wang and D. Duan, Exponential H_∞ filtering for singular Markovian jump systems with mixed mode-dependent time-varying delay, *IEEE Trans on Circuits and Systems-I*, vol. 60, no. 9, pp. 2440-2452, 2013.

    This paper is concerned with the exponential H_∞ filter design for a class of continuous-time singular Markovian jump systems with mixed mode-dependent time-varying delay. By constructing a new Lyapunov-Krasovskii functional, a less conservative delay-dependent bounded real lemma (BRL) is obtained, which guarantees the considered system is exponentially admissible with H_∞ performance. Based on the BRL, the H_∞ filtering problem is solved and an explicit expression of the desired filter can be given. Two numerical examples are presented to illustrate the effectiveness and the potential of the proposed techniques.

38. M. Liu and **P. Shi**, Sensor fault estimation and tolerant control for Itô stochastic systems with a descriptor sliding mode approach, *Automatica*, vol. 49, no. 5, pp. 1242-1250, 2013.

    This paper investigates fault estimation and fault-tolerant control against sensor failures for a class of nonlinear Itô stochastic systems with simultaneous input and output disturbances. By using a new descriptor sliding mode approach, an *accurate estimation of the system states, fault vector and disturbances can be obtained simultaneously. An integral-type sliding mode control scheme is proposed to stabilize the resulting fault system. The reachabilities of the proposed sliding mode surfaces are guaranteed in both the state estimate space and the estimation error space. Finally, a numerical example illustrates the effectiveness and applicability of the proposed technique.*

39. J. Lian, **P. Shi** and Z. Feng, Passivity and passification for a class of uncertain switched stochastic time-delay systems, *IEEE Trans on Cybernetics*, vol. 43, no. 1, pp. 3-13, 2013.

    This paper is concerned with the problems of passivity and passification for a class of uncertain switched systems with stochastic disturbance and time-varying delay. The passivity property is adopted to analyze the influence of the external disturbance to achieve prescribed attenuation levels. Based on average dwell time approach, free-weighting matrix method, and Jensen's integral inequality, sufficient conditions are obtained which ensure the uncertain switched stochastic time-delay system to be robustly mean-square exponentially stable and stochastically passive. Then, the switched passive controllers are synthesized. Finally, two numerical examples illustrate the effectiveness of the proposed methods.

40. **P. Shi**, Y. Yin and F. Liu, Gain-scheduled worst case control on nonlinear stochastic systems subject to actuator saturation and unknown information, *J. of Optimization Theory and Applications*, vol. 156, no. 3, pp. 844-858, 2013.

    This paper proposes a method for designing continuous gain-scheduled worst-case controller for a class of stochastic nonlinear systems under actuator saturation and unknown information. The stochastic nonlinear system is governed by a finite-state Markov process. A gradient linearization procedure is applied to describe such nonlinear systems by several model-based linear systems. Next, the *actuator saturation is transferred into several linear controllers. Moreover, worst-case controllers are established for each linear model. Finally, a continuous gain-scheduled approach is employed to design continuous nonlinear controllers for the whole nonlinear jump system.*

41. **P. Shi**, X. Luan and F. Liu, H_∞ filtering for discrete-time systems with stochastic incomplete measurement and mixed delays, *IEEE Trans on Industrial Electronics*, vol. 59, no. 6, pp. 2732-2739, 2012.

    This paper focuses on the H_∞ filtering problem for a class of discrete-time systems with stochastic incomplete measurement and mixed random delays. A more realistic and accurate measurement mode is proposed to compensate for the negative influence of both missing data and different time delays in a random way. Sufficient conditions for the existence of the admissible filter are derived in terms of linear matrix inequalities, which ensures the asymptotic stability as well as a prescribed H_∞ performance for the filter errors.

42. Z. Wu, M. Cui and **P. Shi**, Backstepping control in vector form for stochastic Hamiltonian systems, *SIAM Journal on Control and Optimization*, vol. 50, no. 2, pp. 925-942, 2012.

    In this paper, the problem of adaptive tracking for a class of stochastic Hamiltonian control systems with unknown drift and diffusion functions is considered. Some difficulties come forth the integral chain consists of vectors, and control and tracking errors are in different channels. An adaptive backstepping controller in vector form is designed such that the closed-loop system has a unique solution that is globally bounded in probability and the fourth moment of the tracking error converges to an arbitrarily small neighborhood of zero. As an application, the modeling and the control for spring pendulum are researched.

43. V. Dragan, H. Mukaidani and **P. Shi**, The linear quadratic regulator problem

for a class of controlled systems modeled by singularly perturbed Itô differential equations, *SIAM J. on Control and Optimization*, vol. 50, no. 1, pp. 448-470, 2012.

This paper discusses an infinite-horizon linear quadratic (LQ) optimal control problem involving state-and control-dependent noise in singularly perturbed stochastic systems. First, an asymptotic structure are newly established. Moreover, sufficient conditions for the existence of the stabilizing solution to the problem are given. A new sequential numerical algorithm for solving the reduced-order AREs is also described. As a result, the proposed control methodology can be applied to practical applications even if the value of the small parameter epsilon is not precisely known.

44. Y. Yin, **P. Shi** and F. Liu, Gain-scheduled robust fault detection on time-delay stochastic nonlinear systems, *IEEE Trans on Industrial Electronics*, vol. 58, no. 10, pp. 4908-4916, 2011.

    This paper studies the problem of continuous gain-scheduled robust fault detection (RFD) on a class of time-delay stochastic nonlinear systems with partially known jump rates. Stochastic linear models and filter-based residual signal generators are constructed in the vicinity of selected operating states. Furthermore, an RFD filter (RFDF) is designed for such linear models by first designing H_∞ filters and then a new performance index. Subsequently, a sufficient condition on the existence of RFDF is established. Finally, a continuous gain-scheduled approach is employed to design continuous RFDFs on the entire nonlinear jump system.

45. **P. Shi** and M. Liu, Discussion On the filtering problem for continuous-time Markov jump linear systems with no observation of the Markov chain, *European J. of Control*, vol. 17, no. 4, pp. 355-356, 2011.

    This paper presented some interesting and useful results in the dynamic linear *filtering for continuous-time linear Markovian jumps systems with additive noise (Wiener process). The proposed filtering scheme is mode-independent, and this paper's main contribution is that an explicit analytical solution can be obtained from the stationary solution associated to a certain Riccati equation. Furthermore, the calculation of the solution of the resulting Riccati equation can be extended to consider convex polytopic uncertainties on the parameters of possible modes of operation of the system and on the transition rate matrix of the Markov process.*

46. M. Liu, **P. Shi**, L. Zhang and X. Zhao, Fault tolerant control for nonlinear Markovian jump systems via proportional and derivative sliding mode observer, *IEEE Trans on Circuits and Systems I: Regular Papers*, vol. 58, no. 11, pp. 2755-2764, 2011.

    This paper investigates the problem of sensor fault estimation and fault-tolerant control for Markovian jump systems. The issues are: i) sensor faults; ii) model Lipchitz nonlinearities; iii) system structure changes governed by Markovian jumping parameters; and iv) time delay in system states. The proposed observer is mode-dependent type in which a derivative gain, a proportional gain and a discontinuous input term are introduced. Employing the developed estimation technique, the asymptotic estimations of system states and sensor faults can be obtained simultaneously. An observer-based fault-tolerant control scheme is developed to stabilize the resulting closed-loop system.

47. L. Wu, **P. Shi** and H. Gao, State estimation and sliding mode control of Markovian jump singular systems, *IEEE Trans on Automatic Control*, vol. 55, no. 5, pp. 1213-1219, 2010.

    This paper is concerned with the state estimation and sliding-mode control problems for continuous-time Markovian jump singular systems with unmeasured states.

Firstly, a new necessary and sufficient condition is proposed, which guarantees the stochastic admissibility of the unforced Markovian jump singular system. Then, the sliding-mode control problem is considered by designing an integral sliding surface function. An observer is designed to estimate the system states, and a sliding-mode control scheme is synthesized. Some conditions for the stochastic admissibility of the overall closed-loop system are derived.

48. L. Zhang and **P. Shi**, Stability, l_2-gain and asynchronous H_∞ control of discrete-time switched systems with average dwell time, *IEEE Trans on Automatic Control*, vol. 54, no. 9, pp. 2193-2200, 2009.

    This paper first investigates the stability and l_2-gain problems for a class of discrete-time switched systems with average dwell time (ADT) switching. The obtained results then facilitate the studies on the issue of asynchronous control. The desired mode-dependent controllers can be designed since the unmatched controllers are allowed to perform in the interval of asynchronous switching before the matched ones are applied. The problem of asynchronous H_∞ control for the underlying systems in linear cases is then formulated. The conditions of the existence of admissible asynchronous H_∞ controllers are derived.

49. L. Hu, **P. Shi** and P. Frank, Robust sampled-data control for Markovian jump linear systems, *Automatica*, vol. 42, pp. 2025-2030, 2006.

    In this paper, we consider the problem of robust control for uncertain sampled-data systems that possess random jumping parameters which is described by a finite-state Markov process. The conditions for the existence of a stabilizing control and optimal control for the underlying systems are obtained. The desired controllers are designed which are in terms of matrix inequalities. Finally, a numerical example is given to show the potential of the proposed techniques.

50. M. Karan, **P. Shi** and Y. Kaya, Transition probability bounds for the stochastic stability robustness of continuous- and discrete-time Markovian jump linear systems, *Automatica*, vol. 42, pp. 2159-2168, 2006.

    This paper considers the robustness of stochastic stability of Markovian jump linear systems in continuous- and discrete-time with respect to their transition rates and probabilities, respectively. The continuous-time (discrete-time) system is described via a continuous-valued state vector and a discrete-valued mode. By using stochastic Lyapunov function approach and Kronecker product transformation techniques, sufficient conditions are obtained for the robust stochastic stability of the underlying systems, which are in terms of upper bounds on the perturbed transition rates and probabilities. Analytical expressions are derived for scalar systems, which are straightforward to use.

51. **P. Shi**, Y. Xia, G. Liu and D. Rees, On designing of sliding mode control for stochastic jump systems, *IEEE Trans on Automatic Control*, vol. 51, no. 1, pp. 97-103, 2006.

    In this note, we consider the stochastic stability and sliding-mode control for linear continuous-time systems with stochastic jumps, in which the jumping parameters are modeled as a continuous-time, discrete-state homogeneous Markov process. Sufficient conditions are proposed to guarantee the stochastic stability of the underlying system. Then, a reaching motion controller is designed to drive the resulting closed-loop system onto the desired sliding surface in a limited time. It has been shown that the sliding mode control problem for the Markovian jump systems is solvable if a set of coupled LMIs has solutions.

52. **P. Shi**, M. Mahmoud, S. Nguang and A. Ismail, Robust filtering for jumping systems with mode-dependent delays, *Signal Processing*, vol. 86, pp. 140-152, 2006.

In this paper, the filtering problem for a class of linear uncertain systems with Markovian jump parameters and functional time delay is examined. The uncertainties are time-varying and norm-bounded parametric uncertainties and the delay factor depends on the mode of operation. We provide complete results for robust weak-dependent stochastic stability and robust linear filter design. Then we extend the theoretical development to the case when a prescribed performance measure is desired. All the results are cast into convenient linear matrix inequality (LMI) forms.

53. **P. Shi**, M. Mahmoud, J. Yi and A. Ismail, Worst case control of uncertain jumping systems with multi-state and input delay information, *Information Sciences*, vol. 176, no. 2, pp. 186-200, 2006.

    In this paper, the problem of H_∞ Control for a class of uncertain systems with Markovian jump parameters and multiple delays is investigated. The jumping parameters are modelled as a continuous-time, discrete-state Markov process and the parametric uncertainties are assumed to be real, time-varying and norm-bounded. The time-delay factors are unknowns and time-varying with known bounds. Complete results for instantaneous and delayed state feedback control designs are developed. The solutions are provided in terms of a finite set of coupled linear matrix inequalities (LMIs).

54. **P. Shi** and Q. Shen, Cooperative control of multi-agent systems with unknown state-dependent controlling Effects, *IEEE Trans on Automation Science and Engineering*, accepted, Jan 2015.

    This paper investigates the cooperative control problem of uncertain high-order nonlinear multi-agent systems on directed graph with a fixed topology. Each follower is assumed to have an unknown controlling effect which depends on its own *state. By the Nussbaum-type gain technique and the function approximation capability of neural networks, a distributed adaptive neural networks-based controller is designed for each follower in the graph such that all followers can asymptotically synchronize the leader with tracking errors being semi-globally uniform ultimate bounded. Analysis of stability and parameter convergence of the proposed algorithm are conducted based on algebraic graph theory and Lyapunov theory. Finally, a example is provided to validate the theoretical results.*

55. H. Wang, **P. Shi** and J. Zhang, Event-triggered fuzzy filtering for a class of nonlinear networked control systems, *Signal Processing*, vol. 113, pp. 159–168, 2015.

    The problem of event-triggered fuzzy filtering is investigated for a class of nonlinear networked control systems in this paper. A logic zero order holder is employed to choose the latest transmitted data packet and discard the disordering packet. Using time-delay system method, the discrete event-triggered communication scheme, the network-induced delay and the nonlinear system are unified into a networked T-S fuzzy time-delay system. Then, a new bounded real lemma is derived for this system based on a reciprocally convex approach.

56. C. Ma, **P. Shi**, X. Zhao and Q. Zeng, Consensus of Euler-Lagrange systems networked by sampled-data information with probabilistic time delays, *IEEE Trans on Cybernetics*, DOI: 10.1109/TCYB.2014.2345735, Jul 2014.

    This paper investigates the consensus problem of multiple Euler-Lagrange systems under directed topology. A more realistic sampled-data communication strategy is proposed. Both of the sampling period and the delays are assumed to be time-varying, which is more general in some practical situations. In addition, the relative coordinate derivative information is not required in the distributed controllers such that the communication network burden can be further reduced. In *particular, the proposed scheme can effectively reduce the energy consumption. By employing the stochastic analysis techniques, sufficient conditions are established to guarantee that the consensus.*

57. F. Li, **P. Shi**, L. Wu, C. C. Lim and M. Basin, Quantized control design for cognitive radio networks modeled as nonlinear semi-Markovian jump systems, *IEEE Trans on Industrial Electronics*, vol. 62, no. 4, pp. 2330-2340, 2015.

    This paper is concerned with the quantized control design problem for a class of semi-Markovian jump systems with repeated scalar nonlinearities. A sufficient condition for associated Markovian jump systems is developed. The existence conditions for full- and reduced-order dynamic output feedback controllers are proposed, and the cone complementarity linearization procedure is employed to cast the controller design problem into a sequential minimization one, which can be solved efficiently with existing optimization techniques. Finally, an application to cognitive radio systems demonstrates the efficiency of the new design method.

58. R. Yang, **P. Shi** and G. Liu, Filtering for discrete-time networked nonlinear systems with mixed random delays and packet dropouts, *IEEE Trans on Automatic Control*, vol. 56, no. 11, pp. 2655-2660, 2011.

    In this technical note, a new class of discrete-time networked nonlinear systems with mixed random delays and packet dropouts is introduced, and the H_∞ filtering problem for such systems is investigated. The mixed stochasitc time-delays consist of both discrete and infinite distributed delays and the packet dropout phenomenon occurs in a random way. Furthermore, new techniques are presented to deal with the infinite distributed delay in the discrete-time domain. Sufficient conditions for the existence of an admissible filter are established, which ensure the asymptotical stability as well as a prescribed H_∞ performance.

59. R. Yang, **P. Shi**, G. Liu and H. Gao, Network-based feedback control for systems

with mixed delays based on quantization and dropout compensation, *Automatica*, vol. 47, no. 12, pp. 2805-2809, 2011.

This paper deals with the problem of feedback control for networked systems with discrete and distributed delays subject to quantization and packet dropout. Both a state feedback controller and an observer-based output feedback controller are designed. It is assumed that system state or output signal is quantized before being communicated. Moreover, a compensation scheme is proposed to deal with the effect of random packet dropout through communication network. Sufficient conditions for the existence of an admissible controller are established to ensure the asymptotical stability of the resulting closed-loop system.

60. X. Luan, **P. Shi** and F. Liu, Stabilization of networked control systems with random delays, *IEEE Trans on Industrial Electronics*, vol. 58, no. 9, pp. 4323-4330, 2011.

    In this paper, an observer-based stabilizing controller has been designed for networked systems involving both random measurement and actuation delays. The developed control algorithm is suitable for networked systems with any type of delays. By the simultaneous presence of binary random delays and using the delay information in the measurement model and controller design, new and less conservative stabilization conditions for networked control systems are derived. The criterion is formulated in the form of a nonconvex matrix inequality of which a feasible solution can be obtained by solving a minimization problem in terms of linear matrix inequalities.

61. R. Yang, G. Liu, **P. Shi**, C. Thomas and M. Basin, Predictive output feedback control for networked control systems, *IEEE Trans on Industrial Electronics*, vol. 61, no. 1, pp. 512-520, 2014.

    This paper studies the problem of predictive output feedback control for networked *control systems (NCSs) with random communication delays. A networked-predictive-control scheme is employed to compensate for the network-induced delay. Furthermore, the time-varying predictive controller with mixed random delays for networked systems is introduced. Then, the system is formulated as a Markovian jump system. New techniques are presented to deal with the distributed delay in the discrete-time domain. Based on the analysis of closed-loop NCSs, the designed predictive time-varying output feedback controller can guarantee system stability.*

62. X. Su, **P. Shi**, L. Wu and S. Nguang, Induced l_2 filtering of fuzzy stochastic systems with time-varying delays, *IEEE Trans on Cybernetics*, vol. 43, no. 4, pp. 1251-1264, 2013.

    This paper is concerned with the problem of induced l_2 filter design for a class of discrete-time Takagi-Sugeno fuzzy Itô stochastic systems with time-varying delays. It focuses on the design of the desired filter to guarantee an induced l_2 performance for the filtering error system. A new comparison model is proposed by employing a new approximation for the time-varying delay state. Then, sufficient conditions for the obtained filtering error system are derived. A desired filter is constructed by solving a convex optimization problem, which can be efficiently solved by standard numerical algorithms.

63. Z. Wu, **P. Shi**, H. Su and J. Chu, Sampled-data exponential synchronization of complex dynamical networks with time-varying coupling delay, *IEEE Trans on Neural Networks and Learning Systems*, vol, 24, no. 8, pp. 1177-1187, 2013.

    This paper studies the problem of sampled-data exponential synchronization of complex dynamical networks (CDNs) with time-varying coupling delay and uncertain sampling. By combining the time-dependent Lyapunov functional approach and convex combination technique, a criterion is derived to ensure the exponential stability of the error dynamics, which fully utilizes the available information about *the actual sampling pattern. Based on the derived condition, the design method of the desired sampled-data controllers is proposed to make the CDNs exponentially synchronized and obtain a lower-bound estimation of the largest sampling interval.*

64. J. Zhang, **P. Shi** and Y. Xia, Fuzzy delay compensation control for T-S fuzzy systems over network, *IEEE Trans on Cybernetics*, vol. 43, no. 1, pp. 259-268, 2013.

    This paper is concerned with the network delay compensation problem for nonlinear networked control systems (NCSs). By taking full advantage of the characteristics of the packet-based transmission in NCSs, new network delay compensation approaches are proposed to actively compensate the network communication delay under the fuzzy control framework. The nonlinear plant is represented by a Takagi-Sugeno fuzzy model, and the predictive control input packets are constructed based on parallel distributed compensation technique. Both state and output feedback fuzzy delay compensation controllers are designed.

65. Z. Wu, **P. Shi**, H. Su and J. Chu, Network-based robust passive control for fuzzy systems with randomly occurring uncertainties, *IEEE Trans on Fuzzy Systems*, vol. 21, no. 5, pp. 966-971, 2013.

    This paper investigates the problem of robust passive control for networked fuzzy systems, where randomly occurring uncertainties, variable sampling intervals, and constant network-induced delay are taken into account. A discontinuous Lyapunov functional is introduced for the closed-loop systems, which takes full advantage of the sawtooth structure of the time-varying interval delay induced by sample-and-hold and signal transmission. A sufficient condition is proposed to ensure the closed-loop system to be robustly stochastically passive. Then, the problem of robust passive control is solved.

66. J. Zhang, Y. Xia and **P. Shi**, Design and stability analysis of networked predictive control systems, *IEEE Trans on Control Systems Technology*, vol. 21, no. 4, pp. 1495-1501, 2013.

    This brief is concerned with the networked predictive control and stability analysis for networked control systems (NCSs) with time-varying network communication delay. By taking the full advantage of the packet-based transmission in NCSs, a state-based networked predictive control approach is proposed to actively compensate the network communication delay. Based on switched system approach, stability analysis result is also established via the average dwell time technique. Finally, the effectiveness of the proposed method is illustrated by a practical experiment.

67. H. Yang, Y. Xia, **P. Shi** and M. Fu, Stability analysis for high frequency networked control systems, *IEEE Trans on Automatic Control*, vol. 57, no. 10, pp. 2694-2700, 2012.

    This note generalizes the stability analysis for a high frequency networked control system. The high-frequency networked control system is described by a delta operator system with a high frequency constraint. Stability conditions are given for the high frequency delta operator system. Furthermore, by developing the generalized Kalman-Yakubovic-Popov lemma, improved stability conditions are also presented in terms of linear matrix inequalities. Some experiment results are presented to illustrate the effectiveness of the developed techniques.

68. X. Su, L. Wu and **P. Shi**, Senor networks with random link failures: distributed filtering for T-S fuzzy systems, *IEEE Trans on Industrial Informatics*, vol. 9, no. 3, pp. 1739-1750, 2013.

    The paper is concerned with the distributed fuzzy filter design for a class of sensor networks described by discrete-time T-S fuzzy systems. We focus on the design *of distributed fuzzy filters to guarantee the filtering error dynamic system to be mean-square asymptotically stable. Sufficient conditions for the obtained filtering error dynamic system are proposed. Based on the measurements and estimates of the system states and its neighbors for each sensor, the solution of the parameters of the distributed fuzzy filters is characterized in terms of the feasibility of a convex optimization problem.*

4. CONCLUSION

This application is based on my research work since 2006 on hybrid dynamical systems, which is still one of the hot and popular topics in automation and control systems design. The submitted publications represent my contributions in the four themes below on hybrid dynamical systems:

1. fuzzy modeling techniques for nonlinear systems analysis, controller and filtering design, in which Tagaki-Sugeno fuzzy model and different approaches have been established to provide rigorous solutions to the design problems.

2. modeling, robust analysis, controller and filter design for dynamical systems with stochastic jumps (in particular, Markovian jumps), in which both linear and nonlinear systems with time-delays and uncertainties are considered, and new approaches are developed to analyze the systems' behavior and conduct the design work.

3. designing more effective neural networks controls by proposing different methods such as dynamic surface, and backstepping, which are independent of any prior knowledge of neural networks.

4. Modeling, analysis and design on networked control systems, and presenting new techniques to overcome different levels of network-induced effects, such as time delays, packet losses and disorder, time-varying packet transmission/sampling intervals, competition of multiple nodes accessing network, data quantization, clock asynchronization among local and remote nodes and network security and safety.

In all above works, some reflect the origin of the subject whilst others have recently emerged. Of course, there are still many open or incompletely solved problems on hybrid dynamical systems which deserve to be continuously investigated further from both theoretic and practical aspects.

It is my hope that my application is sufficient and significant, and satisfies all the criteria required for the degree of Doctor of Engineering at the University of Adelaide.

5. STATEMENT OF AUTHORSHIP

In my view, working with others is essential when researching a multi-disciplinary subject like control and filtering on hybrid dynamical systems. To demonstrate my collaboration with students and peers worldwide, I have deliberately selected most of the papers with 2-4 authors. It is also evident from my full publication list in my CV that I have also conducted a great amount of research work on my own in all the four themes of the subject.

A brief explanation on the authorship of each of the multi-authored submitted publications is as follows:

Publications: 2, 12, 20, 21, 24, 25,, 27, 29–32, 60, 62.

Authorship: Z. Wu, P. Shi, H. Su and J. Chu

I have been collaborating with Profs Wu, Su and Chu (all from Zhejiang University) for a long time. Prof. Wu wrote the draft of the paper. I was partially responsible to the main results' proof in the above papers, and did most of the revision work after reviews.

Publications: 3, 5, 8, 11, 59, 65.

Authorship: X. Su, P. Shi, *et al.*

Prof. Su was my former PhD student. In the above papers, I guided him in completing the main results and simulations.

9. Q. Zhou, P. Shi, S. Xu and H. Li

13. Q. Zhou, P. Shi, J. Lu and S. Xu

26. Q. Zhou, P. Shi, S. Xu and H. Li

28. Q. Zhou, P. Shi, H. Liu and S. Xu

Dr Zhou was one of the visiting scholars in my group and completed the above papers under my supervision. Other authors helped check the paper.

14. J. Zhang, P. Shi and Y. Xia

61. J. Zhang, P. Shi and Y. Xia

63. J. Zhang, Y. Xia and P. Shi

Prof Zhang and Prof Xia are from Beijing Institute of Technology, and we have had a long history of close and successful collaboration. In the above three papers, we shared ideas and discussed many different approaches for the underlying problems.

55. R. Yang, P. Shi and G. Liu

56. R. Yang, P. Shi, G. Liu and H. Gao

58. R. Yang, G. Liu, P. Shi, C. Thomas and M. Basin

Mrs Yang was my former PhD student. I guided her in completing the main results and simulations. Prof Liu suggested some useful approaches and other authors helped check the correctness of the main results.

42. P. Shi and M. Liu

35. M. Liu and P. Shi

43. M. Liu, P. Shi, L. Zhang and X. Zhao

Prof Liu is from Harbin Institute of Technology, and we have had a long history of close and successful collaboration. In the above three papers, we shared ideas and discussed many different approaches for the underlying problems. Profs Zhang and Zhao contributed considerably on the revision.

33. P. Shi, Y. Yin, F. Liu and J. Zhang

37. P. Shi, Y. Yin and F. Liu

I lead the work and wrote the main parts of the above two papers. Others made many useful suggestions.

4. Y. Yin, P. Shi, F. Liu, K. L. Teo and C. C. Lim

41. Y. Yin, P. Shi and F. Liu

Dr Yin was one of the visiting scholars in my group and completed the above two papers under my supervision.

1. F. Li, P. Shi, L. Wu and X. Zhang

54. F. Li, P. Shi, L. Wu, C. C. Lim and M. Basin

Mr Li is my PhD student. In the above papers, I guided him in completing the main results and simulations. Other authors helped check the paper.

19. Q. Shen, P. Shi, T. Zhang and C. C. Lim

51. P. Shi and Q. Shen

I have been collaborating with Dr Shen (From Yangzhou University) for a long time. I was partially responsible to the main results' proof in the above two papers, and did most of the revision work after reviews. Others authors helped check the correctness of the main results.

38. P. Shi, X. Luan and F. Liu

57. X. Luan, P. Shi and F. Liu

I have been working with Dr Luan successfully for many years. She raised the ideas of the work, then we worked together to complete the paper.

49. P. Shi, M. Mahmoud, S. Nguang and A. Ismail

50. P. Shi, M. Mahmoud, J. Yi and A. Ismail

I lead the work and wrote the papers. Prof Mahmoud (Egypt), Prof Nguang (New Zealand), Prof Yi (China), and Prof Ismail (UAE) helped derive some preliminary results and simulations.

7. G. Wang, P. Shi, B. Wang and J. Zhang

15. G. Wang, P. Shi and P. Messenger

Prof Wang presented the ideas and we worked together on this work. Also, I did the revision work.

6. J. Zhang, P. Shi, J. Qiu and S. K. Nguang

Prof Zhang and I made some equal contributions on this work, and Profs Qiu and Nguang did computing examples to verify the main theoretic results obtained.

10. J. Wang, P. Shi, H. Peng, M. J. Perez-Jimenez and T. Wang

My contribution to this work was in discussions and structuring the paper writing.

16. S. K. Nguang, P. Shi and S. Ding

Prof Nguang and I initiated the paper and wrote the paper together, Prof Ding did the revision work.

17. P. Shi, Y. Zhang and R. Agarwal

I proposed the work and wrote the paper. Dr Zhang and Prof Agarwal (USA) helped with many useful ideas and contributed the numerical example parts.

18. C. K. Anh, P. Shi and L. Wu

Profs Anh (Korea) and I closely worked on this paper together, and I contributed considerably on the revision.

22. J. Yu, P. Shi, B. Chen and C. Lin

Dr Yu and I lead the work, and Profs Chen and Lin suggested some useful approaches and helped check the correctness of the main results.

23. L. Zhang, Y. Zhu and P. Shi

My contribution to this work was in discussions and structuring the paper writing.

34. Y. Wang, P. Shi, Q. Wang and D. Duan

Dr Wang and I lead the work, and Profs Wang and Duan suggested some useful approaches and helped check the correctness of the main results.

36. J. Lian, P. Shi and Z. Feng

Dr Lian presented the ideas and we worked together on this work.

39. Z. Wu, M. Cui and P. Shi

My contribution to this work was in discussions and structuring the paper writing. Also, I helped the revision work.

40. V. Dragan, H. Mukaidani and P. Shi

Profs Dragan (Romania) and Morozan (Japan) and I closely worked on this paper together, and I contributed considerably on the revision.

44. L. Wu, P. Shi and H. Gao

Prof Wu and I initiated the paper and wrote the paper together, Prof Gao did the revision work.

45. L. Zhang and P. Shi

Prof Zhang wrote the first version of the paper, then we worked together on it.

46. L. Hu, P. Shi and P. Frank

I have been collaborating with Prof Hu (China) for a long time. I was partially responsible to the main results' proof in the above paper. Prof Frank (Germany) helped check the paper.

47. M. Karan, P. Shi and Y. Kaya

This work was proposed by me, and Dr Karan (USA) played a major role to write the paper. We exchanged the ideas about how to develop the main design algorithms, and worked together on the simulation examples with Dr Kaya (Australia).

48. P. Shi, Y. Xia, G. Liu and D. Rees

I initiated the work and developed the main results in this paper. Dr Xia, Prof Liu and Dr Rees (all from University of Glamorgan) helped with some ideas, did the simulation examples and checked the paper.

Verification of this statement of authorship

From the above statement, it is evident that most of the work presented is based on joint research in which I played either a leading or a major role. In the collaborations and co-authored papers, all involved have brought different and complementary skills and knowledge to the work (ideas, literature reviews, techniques, practical experience, computing simulations). Overall, I submit this as the work of successful international and multi-disciplinary cooperation, in which I have made a distinctive and substantial contribution.

BIBLIOGRAPHY

[1] L. A. Zadeh, "Fuzzy sets," *Inform. Control*, vol. 8, pp. 338–353, 1965.

[2] L. A. Zadeh, "Outline of a new approach to the analysis of complex systems and decision processes," *IEEE Trans. Syst., Man, Cybern.*, vol. SMC-3, no. 1, pp. 28–44, 1973.

[3] R. Babuska, *Fuzzy Modeling for Control*, Boston, MA: Kluwer, 1998.

[4] R. E. Bellman and L. A. Zadeh, "Decision making in a fuzzy environment," *Manage. Sci.*, vol. 17, pp. 141–164, 1970.

[5] J. C. Bezdek, J. M. Keller, R. Krishnapuram and N. R. Pal, *Fuzzy Models and Algorithms for Pattern Recognition and Image Processing*, Boston, MA: Kluwer, 1999.

[6] P. P. Bonissone, V. Badami, et al., "Industrial applications of fuzzy logic at General Electric," *Proc. IEEE*, vol. 38, no. 3, pp. 450–465, Mar. 1995.

[7] T. Takagi and M. Sugeno, "Fuzzy identification of systems and its applications to modeling and control," *IEEE Trans. Syst., Man, Cybern.*, vol. SMC-15, no. 1, pp. pp. 116–132, 1985.

[8] M. Sugeno, "On stability of fuzzy systems expressed by fuzzy rules with singleton consequents," *IEEE Trans. Fuzzy Syst.*, vol. 7, no. 2, pp. 201–224, 1999.

[9] K. Tanaka and H. O. Wang, *Fuzzy Control Systems Design and Analysis: A LMI Approach*, New York: Wiley, 2001.

[10] H. Ying, "General SISO Takagi-Sugeno fuzzy systems with linear rule consequent are universal approximators" *IEEE Trans. Fuzzy Syst.*, vol. 6, no. 4, pp. 582–587, Nov. 1998.

[11] K. Zeng, N. Zhang, and W. Xu,"A comparative study on sufficient conditions for Takagi-Sugeno fuzzy systems as universal approximators" *IEEE Trans. Fuzzy Syst.*, vol. 8, no. 6, pp. 773–780, Dec. 2000.

[12] C. Fantuzzi and R. Rovatti,"On the approximation capabilities of the homogeneous Takagi-Sugeno model" *In Proc. 5th IEEE Int. Conf. Fuzzy Systems*, New Orleans, LA, 1996, pp. 1067–1072.

[13] T. A. Johansen, R. Shorten and R. Murray Smith,"On the interpretation and identification of dynamic Takagi-Sugeno models" *IEEE Trans. Fuzzy Syst.*, vol. 8, no. 3, pp. 297–313, Jun. 2000.

[14] T. M. Guerra and L. Vermeiren, "LMI-based relaxed nonquadratic stabilization conditions for nonlinear systems in the Takagi-Sugeno's form", *Automatica*, vol. 40, no. 5, pp. 823–829, 2004.

[15] M. Feng and C. J. Harris, "Feedback stabilization of fuzzy systems via linear matrix inequalities", *Int. J. Syst. Sci.*, vol. 32, pp. 221231, 2001.

[16] G. Feng and D. Sun, "Generalized H_∞ controller synthesis of fuzzy dynamic systems based on piecewise Lyapunov functions", *IEEE Trans. Circuits Syst. I*, vol. 49, no. 12, pp. 1843–1850, Jun. 2002.

[17] D. J. Choi and P. G. Park, "H_∞ state-feedback controller design for discrete-time fuzzy systems using fuzzy weighting-dependent Lyapunov functions" *IEEE Trans. Fuzzy Syst.*, vol. 11, no. 2, pp. 271–278, Jun. 2003.

[18] C. L. Chen, G. Feng and X. P. Guan, "Delay-dependent stability analysis and controller synthesis for discrete time T-S fuzzy systems with time delays" *IEEE Trans. Fuzzy Syst.*, vol. 13, no. 5, pp. 630–643, Jun. 2005.

[19] S. G. Cao, N. W. Rees and G. Feng,"Analysis and design of fuzzy control systems using dynamic fuzzy state space models" *IEEE Trans. Fuzzy Syst.*, vol. 7, no. 2, pp. 192–200, Jun. 1999.

[20] R. G. Berstecher, R. Palm and H. D. Unbehauen, "An adaptive fuzzy sliding-mode controller" *IEEE Trans. Ind. Electron.*, vol. 48, no. 1, pp. 18–31, Jun. 2001.

[21] R. Boukezzoula, S. Galichet, and L. Foulloy, "Observer-based fuzzy adaptive control for a class of nonlinear systems: Real-time implementation for a robot wrist" *IEEE Trans. Control Syst. Technol.*, vol. 12, no. 3, pp. 340–351, Jun. 2004.

[22] H. Gao, J. Lam, and G. Chen, "New criteria for synchronization stability of general complex dynamical networks with coupling delays," *Physics Letters A*, vol. 360, no. 2, pp. 263–273, 2006.

[23] J. Cao, K. Yuan, H. Li, "Global Asymptotical stability of generalized recurrent neural networks with multiple discrete delays and distributed delays," *IEEE Trans. Neural Networks*, vol. 17, no. 6, pp. 1646–1651, 2006.

[24] J. Cao and J. Wang, "Global asymptotic stability of a general class of recurrent neural networks with time-varying delays," *IEEE Trans. Circuits and Systems (I)*, vol. 50, no. 1, pp. 34–44, 2003.

[25] W. Chen and X. Lu, "New delay-dependent exponential stability criteria for neural networks with variable delays," *Physica-A*, vol. 351, no. 1-2, pp. 53–58, 2006.

[26] W. Chen, X. Lu, Z. Guan and W. Zheng, "Delay-dependent exponential stability of neural networks with variable delay: An LMI approach," *IEEE Trans. Circuits and Systems (II)*, vol. 53, no. 9, pp. 837–842, 2006.

[27] M. Forti, P. Nistri, and D. Papini, "Global exponential stability and global convergence in finite time of delayed neural networks with infinite gain," *IEEE Trans. Neural Netw.*, vol. 16, no. 6, pp. 1449–1463, 2005.

[28] Y. He, M. Wu, and J. She, "An improved global asympotic stability criterion for delayed cellular neural networks," *IEEE Trans. Neural Networks*, vol. 17, no. 1, pp. 250–252, 2006.

[29] Y. He, G. Liu, and D. Rees, "New delay-dependent stability criteria for neural networks with time-varying delay," *IEEE Trans. Neural Networks*, vol. 18, no. 1, pp. 310–314, 2007.

[30] H. Huang, D. W. C. Ho, and J. Lam, "Stochastic stability analysis of fuzzy Hopfield neural networks with time-varying delays," *IEEE Trans. Circuits and Systems (II)*, vol. 52, no. 5, pp. 251–255, 2005.

[31] X. Liao, J. Wang, and Z. Zeng, "Global asymptotic stability and global exponential stability of delayed cellular neural networks," *IEEE Trans. Circuits Syst. II, Exp. Briefs*, vol. 52, no. 7, pp. 403C409, 2005.

[32] V. Singh, "A generalized LMI-based approach to the global asymptotic stability of delayed cellular neural networks," *IEEE Trans. Neural Networks*, vol. 15, pp. 223–225, 2004.

[33] Z. Wang, Y. Liu, and X. Liu, "On global asymptotic stability of neural networks with discrete and distributed delays," *Physics Letters A*, vol. 345, no. 4-6, pp. 299–308, 2005.

[34] Z. Wang, Y. Liu, and X. Liu, "Stability analysis for stochastic cohen-grossberg neural networks with mixed time delays," *IEEE Trans. Neural Networks*, vol. 17, no. 3, pp. 814–820, 2006.

[35] S. Xu and J. Lam, "A new approach to exponential stability analysis of neural networks with time-varying delays," *Neural Netw.*, vol. 19, no. 1, pp. 76–83, 2006.

[36] S. Xu, J. Lam, D. W. C. Ho, and Y. Zou, "Improved global robust asymptotic stability criteria for delayed cellular neural networks," *IEEE Trans. Syst., Man, Cybern. B, Cybern.*, vol. 35, no. 6, pp. 1317–1321, 2005.

[37] S. Xu, J. Lam, D. W. C. Ho, and Y. Zhou, "Novel global asymptotic stability criteria for delayed cellular neural networks," *IEEE Trans. Circuits and Systems (II)*, vol. 48, no. 5, pp. 349–353, 2005.

[38] Z. Wang, Y. Liu, L. Yu, and X. Liu, "Exponential stability of delayed recurrent neural networks with Markovian jumping parameters," *Physics Letters A*, vol. 356, pp. 346–352, 2006.

[39] J. P. Hespanha and A. S. Morse, "Switching between stabilizing controllers," *Automatica*, vol. 38, no. 11, pp. 1905–1917, 2002.

[40] Y. Ji and H. J. Chizeck, "Controllability, stabilizability and continuous-time Markovian jump linear quadratic control," *IEEE Trans. Automat. Contr.*, vol. 35, no. 7, pp. 777–788, 1990.

[41] X. Feng, K. A. Loparo, Y. Ji and H. J. Chizeck, "Stochastic stability properties of jump linear systems," *IEEE Trans. Automat. Contr.*, vol. 37, no. 1, pp. 38–53, 1992.

[42] V. Morio, F. Cazaurang and P. Vernis, "Flatness-based hypersonic reentry guidance of a lifting-body vehicle," *Control Eng. Pract.*, vol. 17, no. 5, pp. 588–596, 2009.

[43] M. Liu, D. W. C. Ho and Y. Niu, "Stabilization of Markovian jump linear system

over networks with random communication delay," *Automatica*, vol. 45, no. 2, pp. 416–421, 2009.

[44] C. E. D. Souza, A. Trofino, and K. A. Barbosa, "Mode-independent H_∞ filters for Markovian jump linear systems," *IEEE Trans. Autom. Contr.*, vol. 51, no. 11, pp. 1837–1841, 2006.

[45] J. Xiong, J. Lam, H. Gao and D. W. C. Ho, "On robust stabilization of Markovian jump systems with uncertain switching probabilities," *IEEE Trans. Autom. Contr.*, vol. 41, no. 5, pp. 897–903, 2005.

[46] B. Du, J. Lam, Y. Zou and Z. Shu, "Stability and stabilization for Markovian jump time-delay systems with partially unknown transition rates," *IEEE Trans. Circuits Syst. I Regul. Pap.*, vol. 60, no. 2, pp. 341–351, 2013.

[47] O. L. V. Costa, J. B. R. do Val and J. C. Geromel, "Continuous-time state-feedback H_2-control of Markovian jump linear system via convex analysis," *Automatica*, vol. 35, no. 2, pp. 259–268, 1999.

[48] J. B. R. do Val, J. C. Geromel and A. P. C. Goncalves, "The H_2-control of jump linear systems: cluster observations of the Markov state," *Automatica*, vol. 38, no. 2, pp. 343–349, 2002.

[49] Y. Cao and J. Lam, "Stochastic stabilizability and H_∞ control for discrete-time jump linear systems with time delay," *J. Franklin Inst.*, vol. 336, no. 8, pp. 1263–1281, 1999.

[50] E. K. Boukas, P. Shi and S. K. Nguang, "Robust H_∞ control for linear Markovian jump systems with unknown nonlinearities," *J. Math. Appl. Appl.*, vol. 282, no. 1, pp. 241–255, 2003.

[51] E. K. Boukas, "H_∞ control of discrete-time Markov jump systems with bounded transition probabilities," *Optim. Control Appl. Met.*, vol. 30, no. 5, pp. 477–494, 2009.

[52] Z. Wu, H. Su and J. Chu, "Delay-dependent H_∞ control for singular Markovian jump systems with time delay," *Optim. Control Appl. Met.*, vol. 30, no. 5, pp. 443–461, 2009.

[53] C. E. de Souza and M. D. Fragoso, "H_∞ filtering for Markovian jump linear systems," *Int. J. Syst. Sci.*, vol. 33, no. 11, pp. 909–915, 2002.

[54] C. E. de Souza and M. D. Fragoso, "H_∞ filtering for discrete-time linear systems with Markovian jumping parameters," *Int. J. Robust Nonlinear Control*, vol. 13, no. 14, pp. 1299–1316, 2003.

[55] Z. Wu, H. Su and J. Chu, "H_∞ filtering for singular Markovian jump systems with time delay," *Int. J. Robust Nonlinear Control*, vol. 20, no. 8, pp. 939–957, 2010.

[56] P. Shi and S. P. Shue, "Robust H_∞ control for linear discrete-time systems with norm-bounded nonlinear uncertainties," *IEEE Trans. Automat. Contr.*, vol. 44, no. 1, pp. 108–111, 1999.

[57] Z. Wang, J. Lam and X. Liu, "Robust filtering for discrete-time Markovian jump delay systems," *IEEE Signal Process Lett.*, vol. 11, no. 8, pp. 659–662, 2004.

[58] J. Liu, Z. Gu and S. Hu, "H_∞ filtering for Markovian jump systems with time-varying delays," *Int. J. Innov. Comput. Inf. Control*, vol. 7, no. 3, pp. 1299-1310, 2011.

[59] S. Xu, T. Chen and J. Lam, "Robust H_∞ filtering for uncertain Markovian jump systems with mode-dependent time-delays," *IEEE Trans. Autom. Control*, vol. 48, no. 5, pp. 900–907, 2003.

[60] X. Yao, L. Wu, W. Zheng and C. Wang, "Robust H_∞ filtering of Markovian jump stochastic systems with uncertain transition probabilities," *Int. J. Syst. Sci.*, vol. 42, no. 7, pp. 1219–1230, 2011.

[61] X. Yao, L. Wu, W. Zheng and C. Wang, "Quantized H_∞ filtering for Markovian jump LPV systems with intermittent measurements," *Int. J. Robust Nonlinear Control*, vol. 23, no. 1, pp. 1–14, 2013.

[62] A. Bemporad, M. Johansson, and M. Heemels, *Networked Control Systems*, Berlin, Germany: Springer, 2010.

[63] D. Hristu-Varsakelis and W. Levine, *Handbook of Networked and Embedded Control Systems*, Boston, MA, Birkhaüser, 2005.

[64] V. Saligrama, *Networked Sensing Information and Control*, New York: Springer, 2008.

[65] T. Yang, "Networked control system: A brief survey," *IET Control Theory Appl.*, vol. 153, no. 4, pp. 403–412, 2006.

[66] P. Antsaklis and J. Baillieul, "Special issue on networked control systems," *IEEE Trans. Autom. Control*, vol. 49, no. 9, pp. 1421–1597, 2004.

[67] L. Bushnell, "Special section on networks and control," *IEEE Control Syst. Mag.*, vol. 21, no. 1, pp. 22–99, 2001.

[68] M. Chow, "Special section on distributed networked-based control systems and applications," *IEEE Trans. Ind. Electron.*, vol. 51, no. 6, pp. 1126–1279, 2004.

[69] F. Lian, "Analysis, design, modeling, and control of networked control systems," Ph.D. dissertation, Mech. Eng. Dept., Univ. of Michigan, Ann Arbor, MI, 2001.

[70] P. Naghshtabrizi, "Delay impulsive systems: a framework formodeling networked control systems," Ph.D. dissertation, Electr. and Comput. Eng. Dept., Univ. of California, Santa Barbara, CA, 2007.

[71] G. C. Walsh, H. Ye, and L. Bushnell, "Stability analysis of networked control systems," *IEEE Trans. Control Syst. Technol.*, vol. 10, no. 3, pp. 438–446, 2002.

[72] W. Zhang, M. Branicky and S. Phillips, "Stability of networked control systems," *IEEE Control Syst. Mag.*, vol. 21, pp. 84–99, 2001.

[73] M. Yu, L. Wang and T. Chu, "Sampled-data stabilization of networked control systems with nonlinearity," *Proc. Inst. Elect. Eng. D*, vol. 152, no. 6, pp. 609–614, 2005.

[74] D. Yue, Q. Han and J. Lam, "Network-based robust H_∞ control of systems with uncertainty," *Automatica*, vol. 41, no. 6, pp. 999–1007, 2005.

[75] J. Nilsson, B. Bernhardsson and B. Wittenmark, "Stochastic analysis and control of real-time systems with random time delays," *Automatica*, vol. 34, no. 1, pp. 57–64, 1998.

[76] F. Yang, Z. Wang, Y. Hung and M. Gani, "H_∞ control for networked systems with random communication delays," *IEEE Trans. Automat. Control*, vol. 51, no. 3, pp. 511–518, 2006.

[77] G. C. Goodwin, H. Haimovich, D. E. Quevedo and J. S. Welsh, "A moving horizon approach to networked control system design," *IEEE Trans. Automat. Control*, vol. 49, no. 9, pp. 1427–1445, 2004.

[78] Z. Wang, F. Yang, D. W. C. Ho and X. Liu, "Robust finite-horizon filtering for stochastic systems with missing measurements," *IEEE Signal Processing Lett.*, vol. 12, no. 6, pp. 437–440, 2005.

[79] R. W. Brockett and D. Liberzon, "Quantized feedback stabilization of linear systems," *IEEE Trans. Automat. Control*, vol. 45, no. 7, pp. 1279–1289, 2000.

[80] H. Ishii and T. Basar, "Remote control of LTI systems over networks with state quantization," *Syst. Control Lett.*, vol. 54, no. 1, pp. 15–31, 2005.

[81] M. Sznaier and A. Sideris, "Feedback control of quantized constrained systems with applications to neuromorphic controllers design," *IEEE Trans. Automat. Control*, vol. 39, no. 7, pp. 1497–1502, 1994.

[82] Y. Tipsuwan and M. Chow, "Control methodologies in networked control systems," *Control Eng. Practice*, vol. 11, no. 10, pp. 1099–1111, 2003.

[83] J. Hespanha, P. Naghshtabrizi and Y. Xu, "A survey of recent results in networked control systems," *Proc. IEEE*, vol. 95, no. 1, pp. 138–162, 2007.

[84] R. Gupta and M. Chow, "Networked control system: overview and research trends," *IEEE Trans. Ind. Electron.*, vol. 57, no. 7, pp. 2527–2535, 2010.

SUMMARY OF PROFESSIONAL CAREER

Dr Peng Shi received the BSc degree in Mathematics from Harbin Institute of Technology, China in 1982; the ME degree in Systems Engineering from Harbin Engineering University, China in 1985; the PhD degree in Electrical Engineering from the University of Newcastle, Australia in 1994; the PhD degree in Mathematics from the University of South Australia in 1998; and the DSc degree from the University of Glamorgan, UK in 2006.

Dr Shi was a lecturer at Heilongjiang University, China, a post-doctorate and lecturer at the University of South Australia; a senior scientist in the Defence Science and Technology Organisation, Australia; and a professor at the University of Glamorgan, UK. Now, he is a professor at the University of Adelaide; and Victoria University, Australia. Dr Shi's research interests include system and control theory, computational and intelligent systems, and operational research. Dr Shi has published over 600 journal articles, and some 200 conference papers. His work has received well over 20000 citations. Among his publications, over 150 papers were published in high impact leading international journals, such as IEEE Transactions, Automatica and SIAM Journals. His H-index is 61 (Web of Science). He is a Highly Cited Researcher from 2003-2013 selected by ISI Thomson Reuters in 2014.

Dr Shi is a Fellow of the Institute of Electrical and Electronics Engineers, the Institution of Engineering and Technology, and the Institute of Mathematics and its Applications. He has been an associate editor or an editorial board member of a number of international journals, including Automatica; IEEE Transactions on Automatic Control; IEEE Transactions on Fuzzy Systems; IEEE Transactions on Cybernetics; IEEE Transactions on Circuits and Systems-I: Regular Papers; IEEE Access; Information Sciences; International Journal of Systems Science; Signal Processing; and Circuits Systems and Signal Processing. Dr Shi was the Chair of Control, Aerospace and Electronic Systems Chapter in the South Australia Section of IEEE; and is now a College of Expert Member with the Australian Research Council.

The following are Dr Shi's ten career-best research outputs:

1. **P. Shi**, E. K. Boukas and R. Agarwal, Control of Markovian jump discrete-time systems with norm bounded uncertainty and unknown delay, *IEEE Trans. on Automatic*

Control, vol. 44, no. 11, pp. 2139–2144, 1999. (Impact Factor: 3.167, 409 citations)

2. **P. Shi**, Y. Xia, G. Liu and D. Rees, On designing of sliding mode control for stochastic jump systems, *IEEE Trans on Automatic Control*, vol. 51, no. 1, pp. 97–103, 2006. (Impact Factor: 3.167, 356 citations)

3. **P. Shi**, E. K. Boukas and R. Agarwal, Kalman filtering for continuous-time uncertain systems with Markovian jumping parameters, *IEEE Trans. on Automatic Control*, vol. 44, no. 8, pp. 1592–1597, 1999. (Impact Factor: 3.167, 277 citations)

4. **P. Shi**, Filtering on sampled-data systems with parametric uncertainty, *IEEE Trans. on Automatic Control*, vol. 43, no. 7, pp. 1022–1027, 1998. (Impact Factor: 3.167, 207 citations)

5. **P. Shi**, Limited Hamilton-Jacobi-Isaacs equations for singularly perturbed zero-sum dynamic (discrete time) games, *SIAM J. on Control and Optimization*, vol. 41, no. 3, 826–850, 2002. (Impact Factor: 1.389)

6. S. K. Nuang and **P. Shi**, H_∞ fuzzy output feedback control design for nonlinear systems: an LMI approach, *IEEE Trans. on Fuzzy Systems*, vol. 11, no. 3, pp. 331–340, 2003. (Impact Factor: 6.306, 271 citations)

7. L. Wu, **P. Shi** and H. Gao, State estimation and sliding-mode control of Markovian jump singular systems, *IEEE Trans. on Automatic Control*, vol. 55, no. 5, pp. 1213–1219, 2010. (Impact Factor: 3.167, 300 citations)

8. L. Zhang and **P. Shi**, Stability, l_2-gain and asynchronous H_∞ control of discrete-time switched systems with average dwell time, *IEEE Trans. on Automatic Control*, vol. 54, no. 9, pp. 2192–2199, 2009. (Impact Factor: 3.167, 229 citations)

9. X. Su, **P. Shi**, L. Wu and Y. Song, A novel approach to filter design for T-S fuzzy discrete-time systems with time-varying delay, *IEEE Trans. on Fuzzy Systems*, vol. 20, no. 6, pp. 1114–1129, 2012. (Impact Factor: 6.306, 240 citations)

10. L. Wu, **P. Shi**, H. Gao, and C. Wang, H_∞ filtering for 2D Markovian jump systems, *Automatica*, vol. 44, no. 7, pp. 1849–1858, 2008. (Impact Factor: 3.132, 232 citations)