Filter design, fault estimation and reliable control for networked time-varying systems: a survey

Jiahui Li\textsuperscript{a, b}, Hongli Dong\textsuperscript{a,b}, Fei Han\textsuperscript{a,b}, Nan Hou\textsuperscript{a,b} and Xuerong Li\textsuperscript{a,b}

\textsuperscript{a}Institute of Complex Systems and Advanced Control, Northeast Petroleum University, Daqing, China; \textsuperscript{b}Heilongjiang Provincial Key Laboratory of Networking and Intelligent Control, Daqing, China

ABSTRACT

This paper is concerned with the overview of the recent progress in filter design, fault estimation and reliable control for networked time-varying systems (NTVSs). Firstly, the concepts of the NTVS, incomplete information, filtering, estimation and control have been introduced. Secondly, the incomplete information phenomena are considered include, but not limited to, communication delays, measurement losses, actuator/sensor faults, signal quantizations and randomly occurring uncertainties. Subsequently, the developments as well as some recent results on filter design, fault estimation and reliable control are reviewed for NTVSs subject to incomplete information in great detail. Finally, conclusions are given and some possible future research directions are pointed out concerning the filtering, estimation and control problems.

ARTICLE HISTORY

Received 16 May 2017
Accepted 12 July 2017

KEYWORDS

Time-varying networked systems; incomplete information; filter design; fault estimation; reliable control

1. Introduction

In the last decades, the progress of computers and communication network technology has a vital impact on the applications of control systems. However, due to the increasing complexity of the controlled plants, the control systems start to develop toward a more decentralized and intelligent direction, accordingly, the traditional point-to-point structure of control systems has been replaced by the private or public networks which can undertake the main transmission task through the components including sensors, controllers and actuators that distributed in different areas. Generally, when there exists a closed-loop control via a communication channel, the controlled systems can be called networked control systems (NCSs) (Walsh, Ye, & Bushnell, 2002). NCSs have many merits over traditional control systems, such as less modularity, easy maintenance, low cost and high reliability. In virtue of its practicability and validity, NCSs are implemented in various fields, for example, in car automation, experimental facilities, medical industry, domestic robots, space exploration, aircraft, automobiles, military systems (Shen, Wang, Liang, & Liu, 2012; Dong, Wang, Chen, & Gao, 2012; Ogren, Fiorelli, & Leonard, 2004; Seiler & Sengupta, 2005; Ding, Wang, & Shen, 2014; Dong, Wang, Alsaadi, & Ahmad, 2015; Li, Shen, Liang, & Shu, 2015; Sheng, Zhang, & Gao, 2014; Montagner, Oliveira, & Peres, 2006), and so on. On the other aspect, it is worth noting that virtually most of the practical engineering systems are time-varying due to that the system parameters are definitely dependent on time, however, such time variations of parameters may result in considerable complexities in the system analysis and synthesis. For this reason, the networked time-varying systems (NTVSs) have become an increasingly hot research field. Give some examples, in Sun, Xie, Xiao, & Soh (2008), Sun (2009), Sun & Xiao (2013) and Shu, Zhang, Shen, & Liu (2016), estimation, filtering and control problems have been investigated for linear discrete NTVSs with random measurement delays or packet dropouts or both.

During the analysis process of NCSs, there is another issue that can not be ignored, that is, the unavoidable incomplete information phenomenon which would seriously degrade the system performance. Two sorts of factors would bring about this phenomenon strikingly. Firstly, the inherent characteristics of the NCSs such as large scale, multiple components, high complexity and wide distribution may lead to higher probabilities of the occurrence of faults in networked systems than in traditional systems. Secondly, since the network is a dynamic system, its quality of service depends on many factors, for example, bandwidth capacity, cable quality and so on. So if the phenomena such as cable aging, interface failures, limited bandwidth and network congestion arise, they will bring negative influences on the application
service of networked systems. For the reasons given above, there is no doubt that the incomplete information phenomenon of NCSs has attracted unprecedented interests in recent years. In this paper, an introduction will be given about the incomplete information phenomena which include communication delays, measurement losses, actuator/sensor faults, signal quantizations and randomly occurring uncertainties.

As is known to all, as one of the fundamental problems, filter design problem has received considerable attention in signal processing and control engineering (Basin, Maldonado, & Karimi, 2011; Basin, Loukianov, & Hernandez-Gonzalez, 2013), and a great many of approaches including Kalman filtering, robust filtering, recursive filtering, $H_\infty$ filtering, gain-scheduling filtering and optimal filtering (Shen, Wang, Shu, & Wei, 2010; Dong, Wang, & Gao, 2010; Hu, Wang, Shen, & Gao, 2013b; Singer, 1970; Shi, Fang, & Yan, 2009; Wang, Liu, Liu, Liang, & Vinciotti, 2009; Wei, Wang, Shen, & Li, 2011; Liu, Wei, Song, & Liu, 2016; Wen, Cai, Liu, & Wen, 2016) have been applied in diverse systems such as uncertain time-delay systems (Wang, Yang, Ho, & Liu, 2006), stochastic systems (Wang et al., 2008) and nonlinear systems (Lam et al., 2005). The overall ideology of filtering problem is to form a type of best estimate for the real value of some certain system based on some potentially noisy observed values (Gao, Meng, & Chen, 2008; Gao, Lam, & Wang, 2005; Gao, Lam, Xie, & Wang, 2005; Meng, Lam, & Fei, 2009; Zhang, Xia, & Shi, 2009). On another research aspect, it is familiar to us that our methods and technologies used in classical or modern control system design are almost under the ideal situation that all system actuators and sensors are in good working conditions. Nevertheless, a number of control systems designed utilizing traditional techniques are unable to satisfy the required performance in the presence of actuator faults, sensor faults and component faults. Even worse, faults would appear at any time in the actual operation of the system, which may generate abnormal production and even make the entire production process stop. Consequently, we must improve the reliability and security of the system to ensure the production process to operate in a safe, reliable and efficient manner. Based on the issues above, the essential problem needs to be settled firstly is to estimate the sizes of faults (Zhang, Ning, & Shi, 2015; Zhang, Zhuang, & Braatz, 2016). After that, in order to maintain the ideal performance, the reliable control is necessary especially in safety-critical systems which should tolerate failures in system components, such as military space mission, aircrafts, nuclear reactors, etc. The study of the design of reliable control systems has gained much attention in the early years, see e.g. Ackermann (1984), Veillette, Medanic, & Perkins (1992) and Vidyasagar & Viswanadham (1985).

Motivated by the above discussions, we aim to timely review the latest progress of the filter design, fault estimation and reliable control problems for NTVSs with incomplete information phenomena. The analysis and synthesis problems of the NTVSs are reviewed firstly. In the same part, the concepts of filter design, fault estimation and reliable control are introduced. Secondly, the recent developments of incomplete information consisting of communication delays, measurement losses, actuator/sensor faults, signal quantizations and randomly occurring uncertainties are discussed. Thirdly, latest results on filter design, fault estimation and reliable control approaches for NTVSs with incomplete information are surveyed in great detail. Finally, conclusions are drawn and some related directions for the further research are pointed out.

The remainder of this paper is organized as follows. In Section 2, the incomplete information phenomena are discussed. In Section 3, the developments of the filter design, fault estimation and reliable control problems for NTVSs with incomplete information are reported. The conclusions as well as some future research topics are presented in Section 4.

2. Incomplete information phenomena

Over the past ten years or so, adequate attention has been paid on the problems of incomplete information focusing on the communication delays, measurement losses, actuator/sensor faults, signal quantizations, randomly occurring uncertainties, etc.

2.1. Communication delays

The communication delays prevalently reside in practical systems, which result from the limited speed of information processing or finite switching speed of amplifiers (Liang, Wang, & Liu, 2010; Hu, Chen, & Du, 2014; Yin, Luo, & Ding, 2014; Liang & Cao, 2007; Zhang, Liu, Fang, & Chen, 2013; Liu, Wang, Zhu, & Liu, 2014). According to the different ways of occurring, delays have been classified into different types, including discrete delays, distributed delays, constant delays and time-varying delays. Owing to the universality and complexity of the time delays, it is significant and challenging to design effective algorithms so as to reduce the impacts from delays on the NCSs. Recently, many efficient methods have been proposed to reduce the conservatism induced by the time delays, for instance, the slack matrix variables technique (Wu et al., 2004), the bounding technique (Moon, Park, Kwon, & Lee, 2001),...
the descriptor system method (Fridman & Shaked, 2002) and the delay-fractioning approach (Peaucelle, Arzelier, Henrion, & Gouaisbaut, 2007; Hu, Wang, Gao, & Stergioulas, 2012b), see Hu, Wang, Chen, & Alsadi (2016) for detail. It should be pointed out that researchers have a passion for the delay-fractioning approach, because when the number of fractions increases or more computational complexity is introduced, the delay-fractioning approach is more efficient than other techniques or methods in reducing the conservatism ascribed to time delays. Fortunately, along with rapid evolution of the computer technology, the computational complexity problem is solvable. Nowadays, the reported delay analysis methods have motivated a lot of interesting researches and a large quantity of papers have been published. It is obvious that, the delays discussed before almost arises continuously, but the communication delays caused by network transmissions may occur stochastically. Accordingly, random communication delays have raised some preliminary concerns, for example, the estimation and filtering problems have been discussed for networked systems with random communication delays (Chen, Xu, & Du, 2016; Dong, Wang, & Gao, 2010; Han, Zhang, & Fu, 2013; Sun & Ma, 2014).

### 2.2. Measurement losses

In networked systems, the phenomenon of measurement losses occurs at a high frequency, and there are many reasons which would generate it. On one hand, the faults in measurement outputs, network jams and accidental sensor failure will result in the packet losses of measurement signals. As we all know, the traditional control, estimation and filtering algorithms assume that the measurement outputs are available all the time, which should be improved due to the possible measurement losses in practical engineering. On the other hand, reflection, refraction and diffraction are inevitable when the signal is transmitted over a wireless channel, and multiple path-induced fading or shadow fading will happen which may severely degrade the characteristic of the system. Based on the facts above, performance analysis and synthesis for networked systems have drawn public attention doubtlessly (Hu et al., 2013b). For instance, the Kalman filtering problem with intermittent observations has been investigated in Sinopoli et al. (2004). In Shu, Lam, & Xiong (2009), the missing data in actuators has been considered for studying the non-fragile exponential stability assignment of discrete-time linear systems. Moreover, the filtering and estimation problems with missing measurements have received high degree of attention, and a lot of research results have been reported (Dong, Wang, Ho, & Gao, 2010; Shen, Wang, & Hung, 2010; Gao & Chen, 2007; Sahebsara, Chen, & Shah, 2007; Sun, Xie, & Xiao, 2008; Wang, Yang, Ho, & Liu, 2005).

### 2.3. Signal quantizations

In the NCSs, quantizer is a device or algorithmic function for the sake of processing the signals which required to be quantized before transmission (Brockett & Liberzon, 2000; Dong, Wang, Ding, & Gao, 2015). Quantization is a process which converts a real-valued signal into a piecewise constant one taking on a finite set of values by the quantizer. There are several reasons which would impact the system behaviour caused by quantization. For one thing, if the signal is out of the range of the quantizer, then the control law designed for the ideal case may lead to instability of the system. The other one is the deterioration of performance near the equilibrium: it is worthwhile to mention that if the distinction between the current and the desired values of the state is small, higher precision is necessary, so asymptotic convergence performance of the system is impossible in this condition. Recently, some methods have been demonstrated in You & Xie (2010), Sharon & Liberzon (2012), Elia & Mitter (2001), Fu & Xie (2005) and You, Sun, Fu, & Xie (2011) to deal with the quantization problems. Up to now, plenty of efforts have been devoted to solve the filtering and fault detection problems for networked systems with signal quantization, and some effective algorithms have been reported (Hu et al., 2013b; Li, Shi, Wang, & Agarwal, 2015; You et al., 2014). For example, in Li, Shi, et al. (2015), the fault detection problem has been addressed for networked control systems with Markovian packet dropouts as well as quantization.

### 2.4. Sensor saturations

In reality, the reason in breaking the high-performance promises of traditional filter theories is that the sensors of system cannot provide signals with unlimited amplitudes as the result of physical or technological constraints. The appearance of the sensor saturations not only limits the filtering performance, but also may lead to unexpected oscillatory behaviour or, even worse, instability of the NCSs. Therefore, the related control and filtering problems have attracted scholars’ interests under sensor saturations, see e.g. Fridman & Dambrine (2009), Cao, Lin, & Chen (2003), Dong, Wang, & Gao (2012) and Ding, Wang, Shen, & Shu (2012). Now, the challenging task is to develop a filtering algorithm by making the utmost use of the available information about the sensor saturations to satisfy the required performance or constraints. Some original results have been reported, such as the sector-bounded approach has been considered to eliminate the effects of sensor saturations (Xiao, Cao, &
the considered phenomena well and characterize their uncertainties. It is generally known that uncertainties commonly exist in practical engineering systems, which are induced by environmental circumstances such as repairs of components and random failures, changing of subsystem interconnections and abrupt environmental disturbances, see Hu et al. (2012b) for detail. In fact, parameter uncertainties always occur in a probabilistic way and a stochastic variable obeying the given Bernoulli distribution can be utilized to account for such kind of phenomenon. This phenomenon can reflect parameter variations in a random way, especially in the network transmission. For example, in the NCSs, the uncertainties may take place according to the randomly changeable network conditions. Therefore, before designing the actual control systems, the random uncertainties should be taken into consideration as an important factor. Recently, in Zhang, Wang, Ding, & Shu (2014), the $H_{\infty}$ fuzzy filtering problem has been investigated for a class of discrete-time Takagi-Sugeno fuzzy systems with randomly occurring uncertainties as well as channel fadeings. In Hou, Dong, Bu, & Yang (2016) and Huo, Chen, & Shen (2017), the estimator has been designed for discrete neural networks with randomly occurring uncertainties and missing measurements, and the event-based robust state estimation problem has been solved in Wang, Fang, & Tian (2017) for discrete time-varying system with uncertain observations and randomly occurring uncertainties. Moreover, to deal with the fault estimation issue with packet dropouts and randomly occurring uncertainties, the recursive approach has been proposed in Song, Hu, Chen, Ji, & Liu (2016).

From the points above, to establish a unified measurement model which reflects different kinds of incomplete information is significant in both theory and practice. However, solving the following identified problems has become a challenging task. First of all, how to comprehend the laws that these recognized phenomena should comply with when they really occur? Then, how can we identify and define the most common type of incomplete information phenomena that occur in the NTVSs? Besides, how to choose a suitable mathematical expression to construct a new measurement model which can describe the considered phenomena well and characterize their occurrence laws?

### 2.5. Randomly occurring uncertainties

In this part, the advances of the filter design, fault estimation and reliable control for networked time-varying systems have come into our vision in parallel to the linear systems. For example, in Ding, Wang, Shen, & Dong (2015) and Guan, Fei, Li, & Xu (2016), the $H_{\infty}$ filters have been constructed respectively for discrete time-varying networked systems with randomly occurring uncertainties and missing measurements. Moreover, in Wang, Dong, & Tian (2017) for discrete time-varying systems with uncertain observations and randomly occurring uncertainties, the recursive approach has been proposed in Song, Hu, Chen, Ji, & Liu (2016).

From the points above, to establish a unified measurement model which reflects different kinds of incomplete information is significant in both theory and practice. However, solving the following identified problems has become a challenging task. First of all, how to comprehend the laws that these recognized phenomena should comply with when they really occur? Then, how can we identify and define the most common type of incomplete information phenomena that occur in the NTVSs? Besides, how to choose a suitable mathematical expression to construct a new measurement model which can describe the considered phenomena well and characterize their occurrence laws?

### 2.5. Randomly occurring uncertainties

It is generally known that uncertainties commonly exist in practical engineering systems, which are induced by environmental circumstances such as repairs of components and random failures, changing of subsystem interconnections and abrupt environmental disturbances, see Hu et al. (2012b) for detail. In fact, parameter uncertainties always occur in a probabilistic way and a stochastic variable obeying the given Bernoulli distribution can be utilized to account for such kind of phenomenon. This phenomenon can reflect parameter variations in a random way, especially in the network transmission. For example, in the NCSs, the uncertainties may take place according to the randomly changeable network conditions. Therefore, before designing the actual control systems, the random uncertainties should be taken into consideration as an important factor. Recently, in Zhang, Wang, Ding, & Shu (2014), the $H_{\infty}$ fuzzy filtering problem has been investigated for a class of discrete-time Takagi-Sugeno fuzzy systems with randomly occurring uncertainties as well as channel fadeings. In Hou, Dong, Bu, & Yang (2016) and Huo, Chen, & Shen (2017), the estimator has been designed for discrete neural networks with randomly occurring uncertainties and missing measurements, and the event-based robust state estimation problem has been solved in Wang, Fang, & Tian (2017) for discrete time-varying system with uncertain observations and randomly occurring uncertainties. Moreover, to deal with the fault estimation issue with packet dropouts and randomly occurring uncertainties, the recursive approach has been proposed in Song, Hu, Chen, Ji, & Liu (2016).

From the points above, to establish a unified measurement model which reflects different kinds of incomplete information is significant in both theory and practice. However, solving the following identified problems has become a challenging task. First of all, how to comprehend the laws that these recognized phenomena should comply with when they really occur? Then, how can we identify and define the most common type of incomplete information phenomena that occur in the NTVSs? Besides, how to choose a suitable mathematical expression to construct a new measurement model which can describe the considered phenomena well and characterize their occurrence laws?

### 3. Filter design, fault estimation and reliable control for networked time-varying systems

In this part, the advances of the filter design, fault estimation and reliable control for NTVSs are systematically reviewed. Here, we emphasize some latest works, including estimation, filtering and control algorithms which have been put forward to reduce the influence of the incomplete information onto the ideal performance under various restrictions.

#### 3.1. Design of various kinds of filter

*Robust/H$_{\infty}$ Filter Design.* The past several years have witnessed the rapid progress and extensive applications of filtering in the real world, such as in spacecraft, navigation, digital image processing, remote sensing technology, signal denoising, target tracking and industrial monitoring, where the Kalman filter is widely deployed. It is worth mentioning that the Kalman filtering approach can be executed only under the assumption that all noise terms and measurements own known distributions and an accurate knowledge of the underlying linear system model is available. However, it is hard to provide the ideal condition under the effects of measurement noises, modelling errors, parameter uncertainties and external disturbance. In this case, the robust/H$_{\infty}$ performance of the networked systems has been paid adequate research attention due to its engineering significance. To mention a few, in Feng, Wang, & Zeng (2011), considering the linear time-varying systems, the robust non-fragile filtering problem has been addressed with multiple packet dropouts and a locally optimal filtering algorithm is established. Specially, in the minimum mean-square error sense, a globally optimal filtering scheme has been proposed in Li, Zhou, & Wu (2013) based on the result in Feng et al. (2011). In view of the missing measurements and quantization effects, the effective H$_{\infty}$ filtering scheme has been presented in Wang, Dong, Shen, & Gao (2013). In addition, the filtering problems for nonlinear time-varying networked systems have come into our vision in parallel to the linear systems. For example, in Ding, Wang, Shen, & Dong (2015) and Guan, Fei, Li, & Xu (2016), the H$_{\infty}$ filters have been constructed respectively for discrete time-varying networked systems with randomly occurring nonlinearities and fading measurements and with time-varying delays, and a further result of a probability-guaranteed H$_{\infty}$ finite-horizon filtering method has been reported in Hu et al. (2012b) for a class of time-varying nonlinear systems with sensor saturations.

*Recursive Filter Design.* In recent years, due to the inevitable nonlinearity problem of practical systems, the analysis and synthesis of nonlinear systems have become
a very active research topic and some results have been published (Hu, Wang, & Gao, 2013; Hu, Wang, Shen, & Gao, 2013a). As mentioned in the last paragraph, the traditional Kalman filtering theory may not satisfy the required performance in the case that the system model is nonlinear even along with uncertainties. For the sake of improving its abilities of handling nonlinearities and uncertainties, many optional methods have been explored in the literature including the robust extended Kalman filter (Hu et al., 2013a; Kai, Wei, & Liu, 2010), $H_\infty$ filtering (Ding, Wang, Shen, et al., 2015; Guan et al., 2016; Hu et al., 2012b), etc. Except for the methods above, the recursive filtering approach which can deal with this kind of problem has stirred an increasing research interest, and some latest results can be given in Feng et al. (2011) and Hu et al. (2013, 2013a, 2013b) and the references therein. In Hu et al. (2013a), the recursive filter has been designed for time-varying nonlinear systems encountering probabilistic sensor delays and finite-step correlated measurement noises. Furthermore, the recursive filter has been constructed for nonlinear time-varying networked systems with multiple missing measurements or quantization measurements. For example, the recursive filtering problem has been developed in Hu et al. (2013) for the nonlinear system with random parameter matrices, correlated noises and multiple fading measurements.

Gain-Scheduling Filter Design. It is not surprising that the gain-scheduling method, as one of the most effective ones for filter design problems of time-varying systems, has been paid more and more attention in the past decade (Hoang, Tuan, Apkarian, & Hosoe, 2004; Liu, Liu, & El Saddik, 2011; Luo, Wei, Karimi, & Wang, 2013; Wei et al., 2011). Its primary thought is to design filter gains as functions of the scheduling parameters, and the gains are assumed to be derived timely. The goal of utilizing parameter-dependent Lyapunov function related gain-scheduling technique is to reduce the possible conservatism Gao, Meng, et al. (2008). Under guaranteed $H_2, H_\infty$ or mixed $H_2/H_\infty$ performance, the $H_2$ and $H_\infty$ discrete-time gain-scheduled filters have been designed in Hoang et al. (2004). An optimal gain scheduling approach has been presented in Liu et al. (2011) to select appropriate external scheduling gain from a deal of optimal gains obtained off-line for the NCSs with packet losses. Moreover, the probability-dependent gain-scheduling filtering problem has also been considered in Wei et al. (2011), and an elegant result has been derived for systems with missing measurements, while a robust $H_\infty$ deconvolution filter has been constructed in Luo et al. (2013) to handle the randomly occurring sensor delays by the probability-dependent method.

It is worth noting that the results of filters design for nonlinear time-varying NCSs with incomplete information are rarely reported compared with the linear ones, and it provides guiding references for future research.

### 3.2. Fault estimation for time-varying networked systems

In practical engineering, faults are undesirable deviations of system parameters from normal states, which are caused by unexpected model uncertainties, time delays, disturbances, perturbations and noises. As the unacceptable deviation will prevent the control system from achieving the desired performance, the fault detection and isolation (FDI) issues are of great significance and have received a wide range of attention, see, e.g. Luo et al. (2015), El-Koujok, Benammar, Meskin, Al-Naemi, & Langari (2014), Park (2010), Yang & Wang (2010), Davoodi, Meskin, & Khorasani (2016), Hu et al. (2016), Jiang, Zhang, & Shi (2011), Shen (2014), Wei, Wang, & Han (2013), Zhong, Zhou, & Ding (2010) and You et al. (2014). However, the difficulty encountered is to get the accurate size of the fault from a FDI scheme (Liu, Cao, & Shi, 2013). Therefore, the fault estimation issue is introduced to derive the size and shape of the faults and reconstruct the fault signals so as to perform the required fault detection automatically (Huang & Yang, 2014).

The key of fault estimation is to design a fault estimator. Regard the input signal and measurable output signal as the inputs of the estimator, and the output signal is the reconstructed fault estimation signal. Moreover, the reconstructed signal can be used as the input signal of the fault-tolerant controller to improve the fault-tolerant performance of the system. Compared with the fault diagnosis method based on residual generation, the fault estimation one can better represent the severity of the fault. In recent years, many researchers in the fields of FDI have been devoted to explore effective fault estimators to obtain the on-line accurate fault information, and plenty of important results have been published. There exist some common methods of fault estimation, including adaptive observer (Li, Shi, Yao, & Wu, 2016), neural network (Zhou, Shi, & Wu, 2016), T-S observer (Shen, Jiang, & Cocquempot, 2014), robust Kalman filter (Hu et al., 2013b), sliding mode observer approach and $H_\infty$ optimization method (Zhang, Jiang, & Shi, 2009; Yan & Edwards, 2007, 2008; Zhang, Swain, & Nguang, 2014; Shen, Steven, & Wang, 2013), and some other excellent fault estimation approaches have been shown in the literature (Park, 2010; Yao, Qin, Wang, & Jiang, 2012; Rodrigues, Hamdi, Theilliolet, Mechmeche, & BenHadj Braiek, 2015; Zhang, Jiang, & Staroswiecki, 2010; Zhang et al., 2015).

In regard to the fault estimation problem for time-varying systems, some efforts have been made to design
fault estimators on a finite time-horizon accompanying with incomplete information. For example, the estimation problems of randomly occurring faults over a finite horizon have been handled in Dong, Wang, Ding, & Gao (2014) for systems with different sources of disturbances via the recursive Riccati difference equation approach, while the recursive matrix inequality method has been utilized in Dong, Wang, Ding, & Gao (2016) to deal with the estimation problem. As is well known, the nonlinearities and uncertainties may make the system modelling complex, therefore, it is necessary to tackle them carefully when analysing the complex dynamical systems under increasing performance requirements (Basin et al., 2013; Ding, Wang, Alsaadi, & Shen, 2015; Ding, Wang, Lam, & Shen, 2015; Dong et al., 2014; Ma, Wang, Lam, Alsaadi, & Liu, 2016). For instance, the fault signal has been estimated in Dong et al. (2014) for a class of time-varying systems with stochastic nonlinearities, and it can be seen that a novel performance requirement against different sources of disturbances has been introduced. Especially mentioned, for the purpose of receiving less conservative results as well as computationally attractive algorithms, the Krein-space approach has been introduced to deal with the finite-horizon fault estimation problems and this method has been proven to be an effective tool to solve the filtering problems with the performance index described by an indefinite quadratic form. To list a few, in Zhong et al. (2010), the $H_\infty$ fault filter has been constructed for linear discrete time-varying systems by using the Krein-space theory. Moreover, in Shen, Ding, & Wang (2013), the measurement delays have been taken into consideration, and a finite-horizon $H_\infty$ fault estimator has been obtained with the help of the Krein-space theory. The robust $H_\infty$ fault estimation problem has been addressed in Shen, Steven, et al. (2013) in the framework of Krein spaces.

Unfortunately, up to now, the fault estimation for nonlinear time-varying NCSs with randomly occurring incomplete information has gained very little research attention despite its practical importance.

### 3.3. Reliable control for networked time-varying systems

In practical control systems especially NCSs, intolerable system performance will appear due to a variety of reasons (changes of working conditions, sensors or actuators aging, zero shift, electromagnetic interference and network disturbance) (Yue, Lam, & Ho, 2003). Therefore, it is practically crucial to design a controller to remain the stability of the system and ensure the system to run properly even the failure exists. Reliable control refers to that no matter there is a failure or not, a controller can always be designed to keep the system stable and meeting certain performance requirements. In recent years, the development of control system is more and more complex, thus enhancing the reliability has attracted public concerns.

Over the past several decades, different methods have been presented so as to satisfy various performance requirements. In Veillette et al. (1992), a methodology has been developed for the design of reliable centralized and decentralized control systems, which meets the $H_\infty$ performance under the conditions not only when all control components are operational, but also when there are sensor or actuator outages in the centralized case or control channel outages in the decentralized case. After that, a procedure has been put forward for the design of reliable linear-quadratic state-feedback controller which guarantees the system stable and a known quadratic performance bound (Veillette, 1995). In addition, a method based on the Hamilton-Jacobi inequality approach has been presented for the design of reliable nonlinear control systems and the $H_\infty$ performance has been taken into account in Yang, Lam, & Wang (1996). In terms of the linear matrix inequality approach, a method has been proposed for designing a reliable fuzzy controller in Chen & Liu (2004) in the sense of asymptotic stability, and the received controller is suitable for the systems whose control components are operating well or in fault.

Along with the methods proposed, a rich body of relevant literature subject to incomplete information or faults issues have been published, see e.g. Gao, Breikin, & Wang (2008), Tian, Yue, & Peng (2010), Tian, Yue, Yang, Gu, & Lu (2011) and Zhang, Su, Pan, Chu, & Wang (2009). The reliable $H_\infty$ control problem has been investigated for discrete-time linear time-varying systems in view of the admissible infinite distributed delays and possible actuator failures in Wang, Wei, & Feng (2009), ensuring that the closed-loop system is exponentially stable with a given disturbance attenuation level $\gamma$. In Tian et al. (2010), the proposed reliable controller has been designed for NCSs with undergoes probabilistic actuator fault, measurements distortion, random network-induced delay and packet dropout. Lately, as a newly emerged research topic, the finite-horizon reliable $H_\infty$ output feedback control problem has been raised for a class of discrete time-varying systems in Dong, Wang, Ding, et al. (2015). The main idea is to design a time-varying output feedback controller over a given finite horizon such that, in the simultaneous presence of randomly occurring uncertainties, randomly occurring nonlinearities and measurement quantization, the closed-loop system achieves a prescribed performance level. In Liu, Gu, & Fei (2016), the reliable control problem has been settled for nonlinear systems with stochastic actuators fault and random disturbances.
delays via a T-S fuzzy model approach. It is worth mentioning that a novel state and sensor fault observer has been proposed in Gao, Breikin, et al. (2008) to estimate system states and sensor faults at the same time, where the considered sensor fault may be in any form, even in the unbounded one.

To the best of our knowledge, there exist only a few results on the reliable control for nonlinear time-varying complex systems with randomly occurring incomplete information, which still remains as a challenging research topic.

The following are some of the open problems that exist in most of the existing results. (1) As we all know, with regard to the designed filters or controllers for time-varying systems, we usually consider that the established filters or controllers are suitable as long as the designed gains are solvable. However, we are unable to give a sufficient condition for its feasibility and this has been an open topic for a long time. (2) Note that, the parameters of time-varying system are variable with time and they are always just given by experience for simulations because we don’t know the changing laws they frequently obey in real-world systems. This is another open problem.

4. Conclusions and future trends

In this paper, we have reviewed some recent advances on filter design, fault estimation and reliable control for NTVSs with incomplete information. Firstly, the analysis and synthesis of the NTVSs have been reviewed. Then, the developments of the incomplete information phenomena have been summarized. Based on these, the latest results on filter design, fault estimation and reliable control for networked time-varying systems with incomplete information have been surveyed. At last, based on the literature review, we give some related topics for the future research works as follows.

(i) Nowadays, the virtual reality technology has been one of the hot research fields, and it is worth considering the reliable control against equipment failure and environmental disturbance.

(ii) Due to that communication protocols may prevent the data from collisions during the signal transmissions, it is a challenging direction to investigate filtering, estimation and control problems for networked time-varying systems with communication protocol.

(iii) Since the security is a ‘hard’ performance index, the analysis in mean-square sense is more conservative for practical engineering. Therefore, the further meaningful work is to solve the security problems with probabilistic performance index in the presence network attacks.

(iv) With the developments of technology, the deep neural network has attracted our attention, furthermore, from the aspect of engineering application, the security issue is critical. Therefore, exploring the fault detection and estimation problem for deep neural networks will be a significant task.

(v) An additional trend for future research is to discuss the applications of the established theories and methodologies to some practical engineering problems such as power systems and artificial intelligence systems.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported in part by the National Natural Science Foundation of China under Grants [grant number 61329301, 61422301 and 61374127], the Northeast Petroleum University Innovation Foundation For Postgraduate [grant number YJSCX2017-026NEPU] and the Alexander von Humboldt Foundation of Germany.

References

Ackermann, J. (1984). Robustness against sensor failures. Automatica, 20, 211–215.

Basin, M. V., Loukianov, A. G., & Hernandez-Gonzalez, M. (2013). Joint state and parameter estimation for uncertain stochastic nonlinear polynomial systems. International Journal of Intelligent Systems, 44(7), 1200–1208.

Basin, M. V., Maldonado, J. J., & Karimi, H. R. (2011). Mean-square filtering for polynomial system states confused with poisson noises over polynomial observations. Modeling, Identification and Control, 32(2), 47–55.

Brockett, R. W., & Liberzon, D. (2000). Quantized feedback stabilization of linear systems. IEEE Transactions on Automatic Control, 45(7), 1279–1289.

Cao, Y.-Y., Lin, Z., & Chen, B. M. (2003). An output feedback $H_{\infty}$ controller design for linear systems subject to sensor nonlinearities. IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications, 50(7), 914–921.

Chen, B., & Liu, X. (2004). Reliable control design of fuzzy dynamic systems with time-varying delay. Fuzzy Sets and Systems, 146, 349–374.

Chen, D., Xu, L., & Du, J. (2016). Optimal filtering for systems with finite-step autocorrelated process noises, random one-step sensor delay and missing measurements. Communications in Nonlinear Science and Numerical Simulation, 32, 211–224.

Davoodi, M., Meskin, N., & Khorasani, K. (2016). Simultaneous fault detection and consensus control design for a network of multi-agent systems. Automatica, 66, 185–194.

Ding, D., Wang, Z., Alsaaedi, F. E., & Shen, B. (2015). Receding horizon filtering for a class of discrete time-varying nonlinear systems with multiple missing measurements. International Journal of General Systems, 44(2), 198–211.

Ding, D., Wang, Z., Lam, J., & Shen, B. (2015). Finite-horizon $H_{\infty}$ control for discrete time-varying systems with randomly
occurring nonlinearities and fading measurements. IEEE Transactions on Automatic Control, 60(9), 2488–2493.

Ding, D., Wang, Z., & Shen, B. (2014). Recent advances on distributed filtering for stochastic systems over sensor networks. International Journal of General Systems, 43(3–4), 372–386.

Ding, D., Wang, Z., Shen, B., & Dong, H. (2015). Envelope-constrained $H_{\infty}$ filtering with fading measurements and randomly occurring nonlinearities: The finite horizon case. Automatica, 55, 37–45.

Ding, D., Wang, Z., Shen, B., & Shu, H. (2012). $H_{\infty}$ state estimation for discrete-time complex networks with randomly occurring sensor saturations and randomly varying sensor delays. IEEE Transactions on Neural Networks and Learning Systems, 23(5), 725–736.

Dong, H., Wang, Z., Alsaaadi, F. E., & Ahmad, B. (2015). Event-triggered robust distributed state estimation for sensor networks with state-dependent noises. International Journal of General Systems, 44(2), 254–266.

Dong, H., Wang, Z., Chen, X., & Gao, H. (2012). A review on analysis and synthesis of nonlinear stochastic systems with randomly occurring incomplete information. Mathematical Problems in Engineering, 2012. Article ID 416358, 15 pages.

Dong, H., Wang, Z., Ding, S. X., & Gao, H. (2014). Finite-horizon estimation of randomly occurring faults for a class of nonlinear time-varying systems. Automatica, 50(12), 3182–3189.

Dong, H., Wang, Z., Ding, S. X., & Gao, H. (2015). Finite-horizon reliable control with randomly occurring uncertainties and nonlinearities subject to output quantization. Automatica, 52, 355–362.

Dong, H., Wang, Z., Ding, S. X., & Gao, H. (2016). On $H_{\infty}$ estimation of randomly occurring faults for a class of nonlinear time-varying systems with fading channels. IEEE Transactions on Automatic Control, 61(2), 479–484.

Dong, H., Wang, Z., & Gao, H. (2010). Robust $H_{\infty}$ filtering for a class of nonlinear networked systems with multiple stochastic communication delays and packet dropouts. IEEE Transactions on Signal Processing, 58(4), 1957–1966.

Dong, H., Wang, Z., & Gao, H. (2012). Fault detection for Markovian jump systems with sensor saturations and randomly varying nonlinearities. IEEE Transactions on Circuits and Systems I: Regular Papers, 59(10), 2354–2362.

Dong, H., Wang, Z., Ho, D. W. C., & Gao, H. (2010). Variance-constrained $H_{\infty}$ filtering for a class of nonlinear time-varying systems with multiple missing measurements: The finite-horizon case. IEEE Transactions on Signal Processing, 58(5), 2534–2543.

El-Koujok, M., Benammar, M., Meskin, N., Al-Naemi, M., & Langari, R. (2014). Multiple sensor fault diagnosis by evolving data-driven approach. Information Sciences, 259(20), 346–358.

Elia, N., & Mitter, S. K. (2001). Stabilization of linear systems with limited information. IEEE Transactions on Automatic Control, 46(9), 1384–1400.

Feng, J., Wang, Z., & Zeng, M. (2011). Optimal robust non-fragile Kalman-type recursive filtering with finite-step autocorrelated noises and multiple packet dropouts. Aerospace Science and Technology, 15(6), 486–494.

Fridman, E., & Dambrine, M. (2009). Control under quantization, saturation and delay: An LMI approach. Automatica, 45(10), 2258–2264.

Fridman, E., & Shaked, U. (2002). A descriptor system approach to $H_{\infty}$ control of linear time-delay systems. IEEE Transactions on Automatic Control, 47(2), 253–270.

Fu, M., & Xie, L. (2005). The sector bound approach to quantized feedback control. IEEE Transactions on Automatic Control, 50(11), 1698–1711.

Gao, H., & Chen, T. (2007). $H_{\infty}$ estimation for uncertain systems with limited communication capacity. IEEE Transactions on Automatic Control, 52(11), 2070–2084.

Gao, H., Lam, J., & Wang, C. (2005). Mixed $H_2/H_\infty$ filtering for continuous-time polytopic systems: A parameter-dependent approach. Circuits Systems and Signal Processing, 24(6), 689–702.

Gao, H., Lam, J., Xie, L., & Wang, C. (2005). New approach to mixed $H_2/H_\infty$ filtering for polytopic discrete-time systems. IEEE Transactions on Signal Processing, 53(8), 3183–3192.

Gao, H., Meng, X., & Chen, T. (2008). A parameter-dependent approach to robust $H_{\infty}$ filtering for time-delay systems. IEEE Transactions on Automatic Control, 53(10), 2420–2425.

Gao, Z., Breikin, T., & Wang, H. (2008). Reliable observer-based control against sensor failures for systems with time delays in both state and input. IEEE Transactions on Systems, Man, and Cybernetics Part A: Systems and Humans, 38(5), 1018–1029.

Guan, C., Fei, Z., Li, Z., & Xu, Y. (2016). Improved $H_{\infty}$ filter design for discrete-time Markovian jump systems with time-varying delay. Journal of the Franklin Institute, 353(16), 4156–4175.

Han, C., Zhang, H., & Fu, M. (2013). Optimal filtering for networked systems with Markovian communication delays. Automatica, 49(10), 3097–3104.

Hoang, N. T., Tuan, H. D., Apkarian, P., & Hosoe, S. (2004). Gain-scheduled filtering for time-varying discrete systems. IEEE Transactions on Signal Processing, 52(9), 2464–2476.

Hou, N., Dong, H., Bu, X., & Yang, F. (2016). State estimation for discrete neural networks with randomly occurring uncertainties and missing measurements. In 2016 12th world congress on intelligent control and automation, Guilin, China, pp. 875–880.

Hu, J., Chen, D., & Du, J. (2014). State estimation for a class of discrete nonlinear systems with randomly occurring uncertainties and distributed sensor delays. International Journal of General Systems, 43(3–4), 387–401.

Hu, J., Wang, Z., Chen, D., & Alsaaadi, F. E. (2016). Estimation, filtering and fusion for networked systems with network-induced phenomena: New progress and prospects. Information Fusion, 31, 65–75.

Hu, J., Wang, Z., & Gao, H. (2013). Recursive filtering with random parameter matrices, multiple fading measurements and correlated noises. Automatica, 49(11), 3440–3448.

Hu, J., Wang, Z., Gao, H., & Stergioulas, L. K. (2012a). Probability-guaranteed $H_{\infty}$ finite-horizon filtering for a class of nonlinear time-varying systems with sensor saturation. Systems & Control Letters, 61(4), 477–484.

Hu, J., Wang, Z., Gao, H., & Stergioulas, L. K. (2012b). Robust sliding mode control for discrete stochastic systems with mixed time-delays, randomly occurring uncertainties and randomly occurring nonlinearities. IEEE Transactions on Industrial Electronics, 59(7), 3008–3015.

Hu, J., Wang, Z., Shen, B., & Gao, H. (2013a). Gain-constrained recursive filtering with stochastic nonlinearities and probabilistic sensor delays. IEEE Transactions on Signal Processing, 61(5), 1230–1238.

Hu, J., Wang, Z., Shen, B., & Gao, H. (2013b). Quantised recursive filtering for a class of nonlinear systems with multiplicative
with known input. *IEEE Transaction on Circuits and Systems-II: Express Briefs*, 60(12), 902–906.

Shen, B., Wang, Z., Shu, H., & Wei, G. (2010). Robust $H_{\infty}$ finite horizon filtering with randomly occurred nonlinearities and quantization effects. *Automatica*, 46(11), 1743–1751.

Shen, Q., Jiang, B., & Cocquempot, V. (2014). Adaptive fuzzy observer-based active fault-tolerant dynamic surface control for a class of nonlinear systems with actuator faults. *IEEE Transactions on Fuzzy Systems*, 22(2), 338–349.

Sheng, L., Zhang, W., & Gao, M. (2014). Relationship between Nash equilibrium strategies and $H_2$/$H_\infty$ control of stochastic Markov jump systems with multiplicative noise. *IEEE Transactions on Automatic Control*, 59(9), 2592–2597.

Shi, Y., Fang, H., & Yan, M. (2009). Kalman filter-based adaptive control for networked systems with unknown parameters and randomly missing outputs. *International Journal of Robust and Nonlinear Control*, 19(18), 1976–1992.

Shu, H., Zhang, S., Shen, B., & Liu, Y. (2016). Unknown input and state estimation for linear discrete-time systems with missing measurements and correlated noises. *International Journal of General Systems*, 45(5), 648–661.

Shu, Z., Lam, J., & Xiong, J. (2009). Non-frugal exponential stability assignment of discrete-time linear systems with missing data in actuators. *IEEE Transactions on Automatic Control*, 54(3), 625–630.

Singer, R. A. (1970). Estimating optimal tracking filter performance for manned maneuvering targets. *IEEE Transactions on Aerospace and Electronic Systems*, AES-6(4), 473–483.

Sinopoli, B., Schenato, L., Franceschetti, M., Poolla, K., Jordan, M. I., & Sastry, S. S. (2004). Kalman filtering with intermittent observations. *IEEE Transactions on Automatic Control*, 49(9), 1453–1464.

Song, Y., Hu, J., Chen, D., Ji, D., & Liu, F. (2016). Recursive approach to networked fault estimation with packet dropouts and randomly occurring uncertainties. *Neurocomputing*, 214, 340–349.

Sun, S. (2009). Linear minimum variance estimators for systems with bounded round measurement delays and packet dropouts. *Signal Processing*, 89(7), 1457–1466.

Sun, S., & Ma, J. (2014). Linear estimation for networked control systems with random transmission delays and packet dropouts. *Information Sciences*, 269, 349–365.

Sun, S., & Xiao, W. (2013). Optimal linear estimators for systems with multiple random measurement delays and packet dropouts. *International Journal of Intelligent Systems*, 44(2), 358–370.

Sun, S., Xie, L., Xiao, W., & Soh, Y. C. (2008). Optimal linear estimation for systems with multiple packet dropouts. *Automatica*, 44(5), 1333–1342.

Sun, S., Xie, L., & Xiao, W. (2008). Optimal full-order and reduced-order estimators for discrete-time systems with multiple packet dropouts. *IEEE Transactions on Signal Processing*, 56(8), 4031–4038.

Tian, E., Yue, D., & Peng, C. (2010). Reliable control for networked control systems with probabilistic actuator fault and random delays. *Journal of the Franklin Institute*, 347(10), 1907–1926.

Tian, E., Yue, D., Yang, T. C., Gu, Z., & Lu, G. (2011). T-S fuzzy model-based robust stabilization for networked control systems with probabilistic sensor and actuator failure. *IEEE Transactions on Fuzzy Systems*, 19(3), 553–561.

Veillette, R. J. (1995). Reliable linear-quadratic state-feedback control. *Automatica*, 31, 137–143.

Veillette, R. J., Medanic, J. B., & Perkins, W. R. (1992). Design of reliable control systems. *IEEE Transactions on Automatic Control*, 37(3), 290–304.

Vidyasagar, M., & Viswanadham, N. (1985). Reliable stabilization using a multi-controller configuration. *Automatica*, 21, 599–602.

Walsh, G. C., Ye, H., & Bushnell, L. G. (2002). Stability analysis of networked control systems. *IEEE Transactions on Control Systems Technology*, 10(3), 438–446.

Wang, S., Fang, H., & Tian, X. (2017). Event-based robust state estimator for linear time-varying system with uncertain observations and randomly occurring uncertainties. *Journal of the Franklin Institute*, 354(3), 1403–1420.

Wang, Z., Dong, H., Shen, B., & Gao, H. (2013). Finite-horizon $H_{\infty}$ filtering with missing measurements and quantization effects. *IEEE Transactions on Automatic Control*, 58(7), 1707–1718.

Wang, Z., Liu, X., Liu, Y., Liang, J., & Vinciotti, V. (2009). An extended Kalman filtering approach to modeling nonlinear dynamic gene regulatory networks via short gene expression time series. *IEEE/ACM Transactions on Computational Biology and Bioin-Formatics*, 6(3), 410–419.

Wang, Z., Liu, Y., & Liu, X. (2008). $H_{\infty}$ filtering for uncertain stochastic time-delay systems with sector-bounded nonlinearities. *Automatica*, 44(5), 1268–1277.

Wang, Z., Wei, G., & Feng, G. (2009). Reliable $H_{\infty}$ control for discrete-time piecewise linear systems with infinite distributed delays. *Automatica*, 45, 2991–2994.

Wang, Z., Yang, F., Ho, D. W. C., & Liu, X. (2006). Robust $H_{\infty}$ filtering for stochastic time-delay systems with missing measurements. *IEEE Transactions on Signal Processing*, 54(7), 2579–2587.

Wang, Z., Yang, F., Ho, D. W. C., & Liu, X. (2005). Robust finite-horizon filtering for stochastic systems with missing measurements. *IEEE Signal Processing Letters*, 12(6), 437–440.

Wei, G., Wang, L., & Han, F. (2013). A gain-scheduled approach to fault-tolerant control for discrete-time stochastic delayed systems with randomly occurring actuator faults. *Systems Science & Control Engineering: An Open Access Journal*, 1, 82–90.

Wei, G., Wang, Z., Shen, B., & Li, M. (2011). Probability-dependent gain-scheduled filtering for stochastic systems with missing measurements. *IEEE Transactions on Circuits and Systems II: Express Briefs*, 58(11), 753–757.

Wen, C., Cai, Y., Liu, Y., & Wen, C. (2016). A reduced-order approach to filtering for systems with linear equality constraints. *Neurocomputing*, 193, 219–226.

Wu, M., He, Y., She, J. H., & Liu, G. P. (2004). Delay-dependent criteria for robust stability of time-varying delay systems. *Automatica*, 40(8), 1435–1439.

Xiao, Y., Cao, Y. Y., & Lin, Z. (2004). Robust filtering for discrete-time systems with saturation and its application to trans-multiplexers. *IEEE Transactions on Signal Processing*, 52(5), 1266–1277.

Yan, X. G., & Edwards, C. (2007). Nonlinear robust fault re-construction and estimation using a sliding mode observer. *Automatica*, 43(9), 1605–1614.

Yan, X. G., & Edwards, C. (2008). Robust decentralized actuator fault detection and estimation for large-scale systems using a sliding mode observer. *International Journal of Control*, 81(4), 591–606.

Yang, F., & Li, Y. (2009). Set-membership filtering for systems with sensor saturation. *Automatica*, 45(8), 1896–1902.
Yang, G. H., Lam, J., & Wang, J. (1996). Reliable controller design for nonlinear system. Proceedings of 35th IEEE conference on Decision and Control, Kobe, Japan, pp. 112–117.

Yang, G. H., & Wang, H. (2010). Fault detection for a class of uncertain state-feedback control systems. IEEE Transactions on Control Systems Technology, 18(1), 201–212.

Yao, L., Qin, J., Wang, H., & Jiang, B. (2012). Design of new fault diagnosis and fault tolerant control scheme for non-Gaussian singular stochastic distribution systems. Automatica, 48, 2305–2313.

Yin, S., Luo, H., & Ding, S. X. (2014). Real-time implementation of fault-tolerant control systems with performance optimization. IEEE Transactions on Industrial Electronics, 61(5), 2402–2411.

You, K., Sun, W., Fu, M., & Xie, L. (2011). Attainability of the minimum data rate for stabilization of linear systems via logarithmic quantization. Automatica, 47(1), 170–176.

You, K., & Xie, L. (2010). Minimum data rate for mean square stabilization of discrete LTI systems over lossy channels. IEEE Transactions on Automatic Control, 55(10), 2373–2378.

You, J., Yin, S., & Gao, H. (2014). Fault detection for discrete systems with network-induced nonlinearities. IEEE Transactions on Industrial Informatics, 10(4), 2216–2223.

Yue, D., Lam, J., & Ho, D. W. C. (2003). Reliable $H_\infty$ control of uncertain descriptor systems with multiple time delays. IEEE Proceedings-Control Theory and Applications, 150(6), 557–564.

Zhang, K., Jiang, B., & Shi, P. (2009). Fast fault estimation and accommodation for dynamical systems. IET Control Theory & Application, 3(2), 189–199.

Zhang, K., Jiang, B., & Staroswiecki, M. (2010). Dynamic output feedback fault tolerant controller design for Takagi-Sugeno fuzzy systems with actuator faults. IEEE Transactions on Fuzzy Systems, 18(1), 194–201.

Zhang, K., Jiang, B., Shi, P., & Xu, J. (2015). Analysis and design of robust $H_\infty$ fault estimation observer with finite-frequency specifications for discrete-time fuzzy systems. IEEE Transactions on Cybernetics, 45(7), 1225–1235.

Zhang, Y., Liu, Z., Fang, H., & Chen, H. (2013). $H_\infty$ fault detection for nonlinear networked systems with multiple channels data transmission pattern. Information Sciences, 221, 534–543.

Zhang, L., Ning, Z., & Shi, P. (2015). Input-output approach to control for fuzzy Markov jump systems with time-varying delays and uncertain packet dropout rate. IEEE Transactions on Cybernetics, 45(11), 2449–2460.

Zhang, D., Su, H., Pan, S., Chu, J., & Wang, Z. (2009). LMI approach to reliable guaranteed cost control with multiple criteria constraints: The actuator faults case. International Journal of Robust and Nonlinear Control, 19(8), 884–899.

Zhang, J., Swain, A. K., & Nguang, S. K. (2014). Simultaneous robust actuator and sensor fault estimation for uncertain nonlinear Lipschitz systems. IET Control Theory & Applications, 8(14), 1364–1374.

Zhang, S., Wang, Z., Ding, D., & Shu, H. (2014). Fuzzy filtering with randomly occurring parameter uncertainties, interval delays, and channel fadings. IEEE Transactions on Cybernetics, 44(3), 406–417.

Zhang, J., Xia, Y., & Shi, P. (2009). Parameter-dependent robust $H_\infty$ filtering for uncertain discrete-time systems. Automatica, 45(2), 560–565.

Zhang, L., Zhuang, S., & Braatz, R. D. (2016). Switched model predictive control of switched linear systems: Feasibility, stability and robustness. Automatica, 67, 8–21.

Zhong, M., Zhou, D., & Ding, S. X. (2010). On designing $H_\infty$ fault detection filter for linear discrete time-varying systems. IEEE Transactions on Automatic Control, 55(7), 1689–1695.

Zhou, Q., Shi, P., Xu, S., & Li, H. (2013). Observer-based adaptive neural network control for nonlinear stochastic systems with time delay. IEEE Transactions on Neural Networks and Learning Systems, 24(1), 71–80.