Real-Time Fault Diagnosis and Fault-Tolerant Control

Nowadays, industrial equipment and systems have become more complex and expensive, with less tolerance for performance degradation, productivity decrease and safety hazards caused by unexpected faults, which stimulate an increasing demand for real-time fault diagnosis and fault tolerant control techniques. Real-time monitoring and fault diagnosis aim to detect, isolate, and identify any kinds of potential abnormalities and faults so that necessary actions can be taken to avoid damage of any components, and even disastrous situations. Fault tolerance is an advanced design/regulation method to ensure the system to work with tolerant performance degradation when some component or parameter faults occur. This kind of techniques is developed for improving system reliability by adopting software (or information) and hardware redundancies. During the last four decades, a huge number of results on fault diagnosis, fault tolerant control and their applications in a variety of engineering systems were reported (e.g., see [1-9] and the references therein). Recent renewable industries such as wind-turbine systems, marine-based energy systems, and photovoltaics energy conversion systems have further simulated the development of research and application of the real-time monitoring, diagnosis and fault-tolerant design. The special session is motivated to provide a forum for academic and industrial communities to report recent theoretic/application results in real-time monitoring, diagnosis and fault-tolerant design, and exchange the ideas about emerging research direction in this field.

Twenty-three papers are eventually selected through a strict peer-review procedure, which represent most recent progress on real-time fault diagnosis, fault-tolerant control design and their applications [10-32]. Twelve selected papers pay attention on fault diagnosis methods and applications [10-21], and the other eleven papers are concentrated on real-time fault tolerant control and applications [22-32]. We are going to overview the selected papers following *fault diagnosis techniques* and *fault-tolerant control techniques* sequentially.

Fault diagnosis techniques can be generally categorized into model-based fault diagnosis, signal-based fault diagnosis, knowledge-based fault diagnosis, and hybrid fault diagnosis (the combination or integration of more than one fault diagnosis methods). All the approaches are based on the information redundancy recorded in the data, and the understanding of the designer on these data. As a result, the categorizations of the fault diagnosis methods rely on what the designers know about the data and how they process the data. For model-based fault diagnosis methods, system models are available to the designer, and the developed model-based algorithms are employed for real-time monitoring and diagnosis using on-line input-output data. For signal-based fault diagnosis, signal pattern for a healthy system is known to the designer, and fault diagnosis is done by checking the consistency between the known healthy signal pattern/feature and the real-time signal pattern/feature, extracted from the real data of the process by using a variety of signal processing techniques. For knowledge-based fault diagnosis, a large amount of historical data is available to the designer. The implicit relationship among the system variables, called knowledge base, can be extracted from the historical data by training or statistical analysis. Fault diagnosis is implemented by checking the consistency between the knowledge base and the real-time feature extracted by using on-line data analysis and learning with the aid of various computational intelligence techniques. It is noticed that all the methods are data based; however, only knowledge based fault diagnosis needs to use a large amount of historical data. Therefore, knowledge-based diagnosis method is also called data-driven fault diagnosis methods (*e.g.*, see the survey paper [10, 11]). The selected research papers [12-21] fall into the respective categories readily (*e.g.*, see Table 1).

TABLE 1
SELECTED FAULT DIAGNOSIS PAPERS IN THE SS

Fault diagnosis methods	Model-based method	Signal-based method	Data-driven method	Hybrid method
Selected papers	[12-14]	[15]	[16-18]	[19-21]

The special session is initialized by the first- and second-part survey papers on real-time fault diagnosis and fault tolerant control contributed by the guest editors [10, 11], which gives a comprehensive review on real-time fault diagnosis techniques and their applications following the categories of model-based fault diagnosis, signal-based fault diagnosis, knowledge-based fault diagnosis, and hybrid and active fault diagnosis. Moreover, an overlook on the future development of the real-time fault diagnosis is presented as well. Over 220 technical literatures are reviewed with more attention on the recent results during the last decade, which sheds a light for the readers from various societies and industrial communities to quickly access to the recent developments of this field.

There are three papers that deal with model-based fault diagnosis methods [12-14], all with applications to wind turbine energy systems. In the paper [12] contributed by Simani *et al.*, Takagi–Sugeno fuzzy model based fault detection and isolation methods are proposed, where the fuzzy models are derived using fuzzy clustering and dynamic system identification techniques. The effectiveness of the proposed approach is tested on the data acquired from the simulated wind turbine benchmark. The paper [13] authored by Sanchez *et al.*, applies a model-based diagnosis approach to an advanced wind turbine benchmark under several fault scenarios by using interval based analytical redundancy relations (static and dynamic) and observers. In most cases, the proposed methods have proven to be able to detect faults with different types (*e.g.,* scaling, offset and stuck) by taking into account modelling errors and measurement noises in the 5MW benchmark. The fault isolation techniques based on column and row reasoning applied to the signature matrix obtained from the simulation tests, have shown that only some of the faults are completely isolable, which deserves a further research in the future. In the paper [14] by Belsa *et al*., fault diagnosis for a wind farm is investigated by using interval parity equations and nonlinear parameter varying models. The noises and modelling errors are assumed to unknown but bounded. The used fault detection test is based on checking the consistency between the measurements and the model to find whether the measurements are inside the interval prediction bounds. The fault isolation algorithm employed is on the basis of analysing the observed fault signatures on-line, and matching them with the theoretical ones obtained using structural analysis. The proposed algorithms are tested on a wind farm benchmark system.

The paper [15], contributed by Zhu *et al*., develops a novel signal-based method for online condition monitoring on micro-milling. The developed online approach directly correlates tool conditions with the force waveform variations, and estimates the tool condition based on the probability densities of the force waveforms singularity measurement. The singularities of the waveforms are measured with holder exponents, which are extracted from their wavelet transform modulus maxima. The experimental studies show that the proposed condition monitoring approach is robust against noises and working condition variations.

The selected papers [16-18] contribute to data-driven fault diagnosis. In [16] by Zhu *et al*., a novel fault classification mechanism is presented by developing probabilistic principal component analyser under hidden Markov model framework. The proposed fault classification method is tested on the Tennessee Eastman benchmark process. The paper [17], contributed by Biswas *et al*., addresses a real-time data-driven algorithm for health diagnosis and prognosis for a circuit breaker trip assembly by using a programmable intelligent electronic device stationed at the remote substation. The comprehensive health detection algorithm has a real time module as well as a predictive module, both of which can provide a clear indication about the present and future health of the circuit breaker trip coil arrangement. The real-time implementation of the proposed algorithm is also illustrated. The paper [18] authored by Chen *et al*., deals with the distributed real-time anomaly detection in networked industrial sensing systems. The proposed method utilizes graph theory and data-driven analysis tools such as principal component analysis. The performance of the proposed algorithm is evaluated by using real data respectively from building structural monitoring and smart grids.

The hybrid fault diagnosis methods are contributed by the selected papers [19-21]. In the paper [19] by Shardt *et al*., model-based and data-driven methods are integrated to do process monitoring. The paper examines the development of soft-sensor-like, data-driven predictor for key performance indicators where the data may not be available at every sampling interval or immediately after sampling. The effectiveness of the proposed method is tested using both Monte Carlo simulations and Tennessee-Eastman process. In [20] by Yin *et al*., an intelligent particle filter is developed for fault detection on nonlinear systems. It is noted that particle filter is an approach between model-based and data-driven techniques, which can estimate the hidden states of the nonlinear and non-Gaussian systems. In order to overcome the particle impoverishment problem suffered by the conventional particle filters, an intelligent particle filter is proposed inspired by the genetic algorithm. The proposed intelligent particle filter is finally used for real-time fault detection on a three-tank system. In [21] by Geest *et al*., inter-turn faults detection in high-speed permanent magnet machines is investigated by using analytical models and signal processing techniques. The proposed fault detection method is suitable for hardware implementation and can function as independent monitor of a drive system. The experiments are also performed to demonstrate the detection performance.

Fault-tolerant control techniques can be generally classified as *passive fault-tolerant control* and *active fault-tolerant control*. The passive fault-tolerant control technique regards the fault as a system perturbation such that the control law is designed to possess inherent fault tolerance capabilities. Therefore, the passive fault-tolerant control needs neither fault diagnosis scheme nor reconfiguration of the controller, which normally has a limit fault-tolerant capability. In contrast, active fault tolerant control is designed to meet the control objectives with minimum system performance degradation either by utilizing a pre-calculated control law or by synthesizing an updating control strategy online. As a result, active fault tolerant control techniques mostly reply on real-time fault diagnosis schemes to provide the up-to-date information on the current status of the system monitored. Undoubtedly, the selected papers [22-31] fall into the category of active fault tolerant control as they are all heavily dependent of the system status information provided by the fault diagnosis schemes. The paper [32] is not based directly on the diagnosis of the faults, but on the compensation of the ultimate impact caused by the faults by using adaptive control laws. Therefore, the paper [32] could belong to the category of the active fault diagnosis as well. As a result, all the selected papers are active fault diagnosis methods (*e.g*., see Table 2), which is an indicator of active fault tolerant control techniques being dominant at present.

TABLE 2
SELECTED FAULT TOLERANCE PAPERS IN THE SS

Fault tolerant control methods	Passive fault-tolerant control methods	Active fault-tolerant control methods
Selected papers	None	[22-32]

Fault-tolerant control in the SS is initialized by the paper [22] contributed by Gao, where a novel simultaneous state and fault discrete-time estimator is proposed by synthesizing descriptor system theory and linear matrix inequality technique, enabling the internal properness and stability of the estimation error dynamics and robustness against the effects from process disturbances and faults. On the basis of the estimated states and faults, the fault tolerance is realized by using actuator and sensor signal compensations. The effectiveness of the proposed algorithms is demonstrated using a vehicle dynamic system.

Descriptor system arises from a natural modelling process which can be utilized to model a wide class of practical systems such as electric and electronic systems, aircraft systems, and biological systems and so forth. In the paper [23] authored by Jia *et al*., fault tolerant control for Takagi-Sugeno fuzzy descriptors with time delays is dealt with. Faults are reconstructed by using learning observers, and fault tolerant control is then implemented by using a feedback control based on the estimated states and reconstructed actuator faults. A truck trailer system is finally employed to verify the proposed methods.

The paper [24], contributed by Alwi *et al*., presents a fault tolerant control scheme for linear parameter varying systems using integral sliding modes and control allocation. The integral sliding mode approach ensures ideal sliding throughout the closed-loop system response and maintains nominal performance and robustness in the face of possible actuator faults/failures. Control allocation can distribute the 'virtual' control signal from the controller to the available redundant actuators especially in the event of faults/failures. The estimate of the actuator efficiency level is used in the fault tolerant control scheme. The proposed method is implemented and evaluated on a research flight simulator in a realistic operating environment.

In the paper [25], authored by Xu *et al*., nonsingular fast terminal sliding-mode fault-tolerant control method is addressed for a second-order nonlinear system, where the estimated value of the actuator fault is available from the fault diagnosis information. By using the proposed method, the closed-loop system can achieve the stabilization mission even when some of the actuators fail to operate. Moreover, the system states of the closed-loop system can converge to the equivalent point in a finite amount of time. The simulation results of a spacecraft attitude control system demonstrate the effectiveness of the proposed schemes.

The paper [26], contributed by Yang *et al*., addresses a real-time fault tolerant control strategy for nonlinear systems. The proposed fault-tolerant control algorithm is based on the internal model control structure with embedded iterative computation, and available estimated faults for signal compensation. The effectiveness of the developed scheme is demonstrated through experimental and simulation results of a three-tank system.

Recently, coordination for multi-agent systems has received much attention due to its emerging applications in sensor networks, spacecraft formation flying, and so forth. Consensus tracking means that a group of agents reaches an agreement with the leader on a common value by interacting with their local neighbors, and the leader can move following the pre-defined trajectory. For large-scale multi-agent networks, actuators in every single agent may not work in the ideal way due to unexpected malfunctions, which motivates to develop effective design methodologies to accommodate potential component failures and maintain the system stability with tolerable performance degradation. In the paper [27], authored by Zuo *et al*., fault tolerant consensus tracking problems for both linear and Lipschitz nonlinear multi-agent systems are investigated. In order to compensate actuator failure effects on the consensus tracking, an adaptive fault tolerant control protocol is presented by estimating the faults and updating state feedback gain online.

Fault-hiding paradigm is an active strategy for fault tolerance, where the faulty plant is reconfigured instead of the controller/observer, and a reconfiguration block is inserted when a fault occurs. The reconfiguration block is selected so as to hide the fault from the viewpoint of the controller, allowing it to see the same plant as before the fault. The reconfiguration block is called virtual actuator in case of actuator faults. In the paper [28] by Rotondo *et al*., fault-hiding approach is applied to the fault-tolerant control of a four wheeled omnidirectional robot, which is modelled as quasi-linear parameter varying system. A switching linear parameter varying virtual actuator is added to the control loop to realize fault tolerance for the system under the effect of actuator faults. The effectiveness of the proposed approach is demonstrated through experimental results obtained with a real test-bed.

The paper [29], contributed by Cecati *et al*., presents a fault tolerant approach for three-phase voltage inverters. A generalized switching function accounting for both healthy and faulty conditions is proposed, and a simple and feasible method to embed fault diagnosis and reconfiguration within the control algorithm is addressed. Experimental results by using a test bench composed of a dSPACE control board and INFRANOR BF70/4.22 converter demonstrate the effectiveness and feasibility of the proposed fault-tolerant control strategy.

Multi-level converters can have applications in high-voltage high-power renewable energy systems, which could operate under fault conditions in case of a loss of a branch or voltage cell, owing to the multi-branch structure. This motivates to develop an effective fault tolerant control strategy for multi-level converters. In the paper [30], authored by Li *et al*., a novel active fault tolerant space vector pulse width modulation (SVPWM) strategy is proposed for three-phase multi-level converters under single-phase faults. The proposed modulation strategy treats the multilevel converter as a two-level converter by introducing an offset vector to adjust the modulation of the converter online under different fault conditions. The effectiveness of the proposed fault tolerant scheme is verified on a seven-level hybrid input-switched converter under several scenarios.

Industrial wireless sensor networks normally operate in challenging environments due to dust, heat, water, electromagnetic interference and interference from other wireless devices, therefore it is difficult to ensure a reliable real-time communication for industrial wireless sensor networks. In [31] by Yang *et al*., three independent methods, that is, segmented slot assignment, fast slot competition and free node scheduling, are addressed in order to improve the reliability of the real-time communication. The proposed algorithms support efficient slot re-scheduling caused by link or node failure. The proposed methods are demonstrated by using simulations and a real implementation targeting monitoring of welder machines.

The special session is ended by the paper [32] contributed by Wang *et al*., which addresses a robust adaptive fault tolerant consensus protocol for multi-agent systems subjected to unknown nonlinear dynamics and unexpected actuator faults. By introducing the virtual parameter estimation error into the Lyapunov function candidates, the proposed adaptive control algorithms are capable of compensating uncertain dynamics, rejecting disturbances, accommodating actuation faults, and ensuring uniformly ultimately bounded synchronization for the multi-agent system under such anomaly conditions. The proposed fault tolerant control method is not based directly on the diagnosis of the faults, but on the compensation of its ultimate impact, and such impact has been reflected in the part of the lumped uncertainties in the system.

To this end, the overview of the 22 selected papers of the special session ``Real-Time Fault Diagnosis and Fault-Tolerant Control'' have been accomplished, which have reflected most recent progress in the research field. We hope this special session can further stimulate the research interests in this direction from a variety of societies and industrial sessions. More effective monitoring, diagnosis and tolerant control methods/algorithms with real-time implementations are expected.

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References

[1] A. Willsky, ``A survey of design methods for failure detection in dynamic systems,'' *Automatica*, vol.12, no.6, pp.601-611, Nov. 1976.

[2] J. Gertler, ``Survey of model-based failure detection and isolation in complex plants,'' *IEEE Contr. Syst. Mag*., vol.8, no.6, pp.3-11, Dec. 1988.

[3] P. Frank, ``Fault diagnosis in dynamic systems using analytical and knowledge-based redundancy-A survey and some new results,'' *Automatica*, vol.26, no.3, pp.459-474, May 1990.

[4] J. Chen, and R. Patton, Robust Model-Based Fault Diagnosis for Dynamic Systems. Boston, MA, USA: Kluwer Academic, 1999.

[5] M. Blanke, M. Kinnaert, J. Lunze, and M. Staroswiecki, Diagnosis and Fault-Tolerant Control. Berlin, Germany: Springer, 2003.

[6] S. X. Ding, Model-based Fault Diagnosis Techniques: Design Schemes, Algorithms, and Tools. Berlin, Germany: Springer, 2008.

[7] R. Isermann, Fault-Diagnosis Applications. Berlin, Germany: Springer, 2008.

[8] Z. Gao, H. Saxen, and C. Gao, ``Special section on data-driven approaches for complex industrial systems,'' *IEEE Ind. Inf*., vol.9, no.4, pp.2210-2212, Nov. 2013.

[9] B. Mirafzal, ``Survey of fault-tolerance techniques for three-phase voltage source inverters,'' *IEEE Trans. Ind. Electron*., vol.61, no.10, pp.5192-5202, Oct. 2014.

[10] Z. Gao, C. Cecati, and S. X. Ding, ``A survey of fault diagnosis and fault-tolerant techniques part I: fault diagnosis with model-based and signal-based approaches,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[11] Z. Gao, C. Cecati, and S. X. Ding, ``A survey of fault diagnosis and fault-tolerant techniques part II: fault diagnosis with knowledge-based and hybrid/active approaches,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[12] S. Simani, S. Farsoni, and P. Castaldi, ``Fault diagnosis of a wind turbine benchmark via identified fuzzy models,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[13] H. Sanchez, T. Escobet, V. Puig, P. Odgaard, ``Fault diagnosis of an advanced wind turbine benchmark using interval-based ARRs and observers,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[14] J. Belsa, P. Jimenez, D. Rotondo, F. Nejjari, and V. Puig, ``An interval NLPV partiy equations approach for fault detection and isolation of a wind farm,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[15] K. Zhu, T. Mei, and D. Ye, ``Online condition monitoring in micro-milling: A force waveform shape analysis approach,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[16] J. Zhu, Z. Ge, and Z. Song, ``HMM-driven robust probabilistic principal component analyzer for dynamic process fault classification,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[17] S. Biswas, A. Srivastava, and D. Whitehead, ``A real-time data-driven algorithm for health diagnosis and prognosis of a circuit breaker trip assembly,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[18] P. Chen, S. Yang, and J. McCann, ``Distributed real-time anomaly detection in networked industrial sensing systems,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[19] Y. Shardt, H. Hao, and S. X. Ding, ``A new soft-sensor-based process monitoring scheme incorporating infrequent KPI measurements,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[20] S. Yin, and X. Zhu, ``Intelligent particle filter and its application on fault detection of nonlinear systems,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[21] M. Geest, H. Polinder, J. Ferreira, A. Veltman, J. Wolmarans, and N. Tsiara, ``Analysis and neutral voltage based detection of inter-turn faults in high-speed permanent magnet machines with parallel strands,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[22] Z. Gao, ``Fault estimation and fault tolerant control for discrete-time dynamic systems,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[23] Q. Jia, W. Chen, Y. Zhang, and H. Li, ``Fault reconstruction and fault-tolerant control via learning observers in Takagi-Sugeno fuzzy descriptor systems with time delays,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[24] H. Alwi, C. Edwards, O. Stroosma, J. Mulder, and M. Hamayun, ``Real-time implementation of an ISM fault tolerant control scheme for LPV plants,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[25] S. Xu, C. Chen, and Z. Wu, ``Study of nonsingular fast terminal sliding-mode fault-tolerant control,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[26] Y. Yang, L. Li, and S. X. Ding, ``A control-theoretic study on Runge-Kutta methods with application to real-time fault-tolerant control of nonlinear systems,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[27] Z. Zuo, J. Zhang, and Y. Wang, ``Adaptive fault tolerant tracking control for linear and Lipschitz nonlinear multi-agent systems,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[28] D. Rotondo, V. Puig, F. Nejjari, and J. Romera, ``A fault-hiding approach for the switching quasi-LPV fault tolerant control of a four wheeled omnidirectional mobile robot,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[29] C. Cecati, A. Tommaso, F. Genduso, R. Miceli, and G. Galluzzo, ``Comprehensive modelling and experimental testing of fault detection and management of a non-redundant fault-tolerant VSI,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[30] X. Li, S. Dusmez, B. Akin, and K. Rajashekara, ``A new active fault tolerant SVPWM strategy for single phase faults in three-phase multilevel converters,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[31] D. Yang, Y. Xu, H. Wang, T. Zheng, H. Zhang, H. K. Zhang, and M. Gidlund, ``Assignment of segmented slots enabling reliable real-time transmission in industrial wireless sensor networks,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

[32] Y. Wang, Y. Song, and F. Lewis, ``Robust adaptive fault-tolerant control of multi-agent systems with uncertain non-identical dynamics and undetectable actuator failures,'' *IEEE Trans. Ind. Electron.*, vol.62, no.6, Jun. 2015.

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