Digital Object Identifier 10.1109/ACCESS.2020.2980404

EDITORIAL

IEEE ACCESS SPECIAL SECTION EDITORIAL: DATA-DRIVEN MONITORING, FAULT DIAGNOSIS AND CONTROL OF CYBER-PHYSICAL SYSTEMS

It is well known that cyber-physical systems (CPSs) commonly exist in both industrial manufacturing and people's daily lives. As a hot topic within Industry 4.0, CPSs have attracted interest from both academia and industry. Typical examples of CPSs include autonomous vehicles, smart grid, process control systems, and industrial robotics systems. The traditional techniques are mainly focused on either the physical object or the abstract data model individually. A simultaneous consideration of both domains is needed.

Conventional methods of fault diagnosis and control require analytical system models, which are established based on either the physical constraints or identification techniques. The feasibility and complexity of these approaches vary significantly among specific applications, and the monitoring performance relies heavily on the model precision. On the other hand, data-driven approaches provide a potential solution to large-scale complex systems with better reliability. The motivation of the big data-driven practical solutions originates from the rapid development of digitalized sensors, storage techniques, and other information infrastructures, which provide colossal but redundant system information. Consequently, the greatest problem is designing universally feasible solutions to ascertain CPS behavior and to perform fault diagnosis and control design based on the characteristics extracted from the databases and the real-time measurements.

The primary objective of this Special Section in IEEE ACCESS is to provide an international forum for scientists, engineers, and practitioners working on the field of data-drivenn CPS monitoring, fault diagnosis, and control design, to exchange their latest achievements and to identify critical issues and challenges. After a rigorous review process, we accepted 46 articles to form the Special Section.

The 46 articles included in this Special Section (Data-Driven Monitoring, Fault Diagnosis and Control of Cyber-Physical Systems) mainly focus on the following topics: advanced approaches for CPS monitoring; data-driven CPS fault detection, isolation, and diagnosis methods; new data-driven CPS model description and modeling techniques; robust data-driven optimization algorithms for CPSs; CPS-oriented robust control and fault-tolerant control; unified framework for CPS formulation and analysis; data-driven artificial intelligence approaches applied in CPS; and challenges and techniques for potential industrial and domestic applications.

Among the accepted articles in this Special Section, ten articles paid attention to the problem of advanced approaches for CPS monitoring. Focused on the data-driven nonfragile filtering problem for the cyber-physical system, Lyu *et al.*, considered randomly occurring gain variations (ROGVs) to account for the parameter fluctuations occurring during the filter implementation, in the article ''Data-driven robust nonfragile filtering for cyber-physical systems.'' Another article, ''Prognostics for a leaking hydraulic actuator based on the F-distribution particle filter,'' by Guo and Gan, also focused on the filtering problem and presented a novel technique, namely, the F-distribution particle filter-based prognostics, following the principle that the particles' weights were calculated dynamically by the F kernel rather than keeping it fixed in the state prediction phase. Jiang *et al.*, investigated the current status of research in ICPS monitoring and control, and reviewed the recent advances in monitoring, fault diagnosis, and control approaches based on data-driven realization in the article, ''Data-driven monitoring and safety control of industrial cyber-physical systems: basics and beyond.'' The practical requirements in the typical ICPS applications were summarized as the major issues to be addressed for the monitoring and the safety control tasks. The key challenges and the research directions were proposed as references to future work.

In the article, ''An improved principal component regression for quality-related process monitoring of industrial control systems,'' by Sun and Hou, an improved principal component regression (IPCR) was proposed. Compared with the conventional method, IPCR can represent the relationship between the fault and product quality more clearly. In the article, ''A new BRB model for cloud security-state prediction based on the large-scale monitoring data,'' Wei *et al.*, proposed a double-layer method for predicting the security state of cloud computing systems based on Belief Rule Base (BRB) model, where the Evidential Reasoning (ER) algorithm was employed to fuse the multiple system indicators of the actual cloud system, and made a reasonable assessment to describe the cloud security state. This method can utilize quantitative and qualitative information simultaneously.

Wang *et al*., proposed a multiset canonical correlation analysis (MCCA)-based joint-individual monitoring scheme for parallel-running batch processes in the article ''Joint-individual monitoring of parallel-running batch processes based on MCCA.'' The scheme considered the individual feature of each batch process and the joint features shared by all batch processes. In addition, Chen *et al*., presented a new modeling and monitoring framework to avoid the traditional Bayesian network disadvantage in the article, ''Process monitoring based on multivariate causality analysis and probability inference.'' In the article, ''Temporal-spatial global locality projections for multimode process monitoring,'' by Song and Shi, an original algorithm named temporal-spatial global locality projections (TSGLP) was proposed to construct a single model which can monitor multimode processes directly.

In the article, ''Minimum-variance unbiased unknown input and state estimation for multi-agent systems by distributed cooperative filters,'' Liu *et al*., addressed the problem of the simultaneous estimation of unknown inputs and states in a multi agent system with time-invariant and time-varying topology. In the article ''Data-driven human-robot coordination based walking state monitoring with cane-type robot'' by Yan *et al*., the existence of human-robot coordination state was first statistically verified in the process of using a walking-aid cane-type robot during walking. Based on this coordination, a new walking state monitoring method was proposed using the principal component analysis (PCA). Li *et al*., proposed a process modeling and monitoring method with incomplete data based on the robust PPLS method in the article, ''Process modeling and monitoring with incomplete data based on robust probabilistic partial least square method.''

This Special Section also addresses the problem of data-driven CPS fault detection, isolation, and diagnosis methods. In the article ''Data-driven inter-turn short circuit fault detection in induction machines,'' by Xu *et al*., a data-driven on-line fault detection framework, incorporated with multi feature extraction/selection and multi classifier ensemble was proposed, capable of detecting ITSC faults in IMs that are subjected to variable operating conditions. With the increased diversity of the base learners, the fault detection accuracy can be enhanced and the robustness can be guaranteed. In another article, ''Data-driven diagnosis of cervical cancer with support vector machine-based approaches,'' by Wu and Zhou, the support vector machine (SVM) approach was introduced for cervical cancer diagnosis. Zhang *et al*., proposed a novel approach to fault detection for nonlinear processes based on a manifold learning in the article, ''Fault detection based on modified Kernel semi-supervised locally linear embedding.'' Then, in the article, ''Joint data-driven fault diagnosis integrating causality graph with statistical process monitoring for complex industrial processes,'' Dong *et al*., proposed an integrated fault diagnosis method to deal with fault location and propagation path identification. The authors Hou and Xiao made an in-depth investigation of the dominant sets algorithm in the article ''A data-driven clustering approach for fault diagnosis.'' It can be observed that this algorithm is dependent on the similarity parameter in constructing the pairwise similarity matrix, and has the tendency to generate spherical clusters only.

In the article, ''Diagnosis of gear faults by using the linear canonical transform in acceleration and deceleration processes,'' Shuiqing *et al*., used the LCT instead of the FT- based methods to diagnose the gear faults in the acceleration and deceleration processes. Wang and Jiao focused on the issue of quality-related fault detection and diagnosis in the articles, ''Quality-related fault detection and diagnosis based on total principal component regression model'' and ''Nonlinear fault detection based on an improved Kernel approach.'' To overcome the disadvantages of the least squares twin support vector hypersphere (LS- TSVH), some improvements were proposed by Ai *et al*., in the article, ''A multi-class classification weighted least squares twin support vector hypersphere using local density information.''

In ''A new safety assessment method based on evidential reasoning rule with a prewarning function,'' by Zhao *et al*., a new safety assessment method based on evidential reasoning rule (ER rule) with a prewarning function was proposed. In the article, ''A fault detection and health monitoring scheme for ship propulsion systems using SVM technique,'' Zhou *et al*., formulated the well-established observer-based residual generator to construct multiple evaluation functions, which were employed as the classification features of the support vector machine (SVM) for fault detection. In the article, ''A new belief-rule-based method for fault diagnosis of wireless sensor network,'' He *et al*., proposed a method for fault diagnosis of WSN based on a belief rule base (BRB) model. Qin *et al*., explored a new automatic sparse representation method for detecting weak transients in the article, ''Adaptively detecting the transient feature of faulty wind turbine planetary gearboxes by the improved Kurtosis and Iterative Thresholding Algorithm.'' Focused on the problem of parity space-based fault diagnosability analysis for linear discrete-time systems, Song *et al*., presented the article, ''An alternative parity space-based fault diagnosability analysis approach for linear discrete time systems.'' To deal with the fault of the vehicle platoon, Wang *et al*., established a fault detection and isolation (FDI) system with a two-level fault diagnosis architecture in the article, ''Two-level fault detection and isolation algorithm for vehicle platoon.''

The problem of new data-driven CPS model description and modeling techniques also is addressed. The article, ''Extended crossover model for human-control of fractional order plants,'' by Martinez-Garcia *et al*., proposed a data-driven generalization of the crossover mode, characterizing the human control of systems with both integer and fractional-order plant dynamics. In this article, a deeper analysis of the data shows that human response is more closely correlated to fractional-order representations of visual cues, rather than directly to objective engineering variables, as is commonly proposed in human control models in

the literature. In another article, ''Time sequential phase partition and modeling method for fault detection of batch processes'' by Ye *et al*., a new adaptive phase partition and online fault detection method was proposed to track the phase transition by time sequence. Yan *et al*., explored a novel idea for power equipment monitoring and found that random matrix theory was suitable for modeling the massive data sets in this situation in ''Big data modeling and analysis for power transmission equipment: A novel random matrix theoretical approach.'' In the article, ''Hybrid prediction method for the electromagnetic interference characteristics of printed circuit boards based on the equivalent dipole model and the finite-difference time domain method,'' by Zhang *et al*., a hybrid modeling method for analyzing the electromagnetic compatibility characteristics of printed circuit boards (PCBs) was proposed. The proposed method uses an equivalent magnetic dipole array deduced from near-field scanning results obtained at a certain height over the PCB surface under test and the finite-difference time-domain (FDTD) algorithm.

Robust data-driven optimization algorithms for CPS is a hot topic. In the article, ''A multi-step source localization method with narrowing velocity interval of cyber-physical systems in buildings,'' Dong *et al.,* proposed a multi step localization method (MLM) without premeasured velocity for heterogeneous and complex propagation media. The velocity interval used for localization is narrowed and optimized continuously through the multi step localization, where the optimal velocity interval is determined when the velocity differences are less than the threshold. In the article, ''Optimal control for zinc electrowinning process with current switching,'' by Yang *et al*., the optimal control problem for the zinc electrowinning process during the current switching period was investigated. The proposed method is successfully applied to the electrowinning process of a zinc hydrometallurgy plant in China. Luo *et al*., focused on how to choose an appropriate value of every parameter in the article, ''Multi-parameter-setting based on data original distribution for DENCLUE optimization.'' The highlight of the method is that the selection of parameters no longer depends on personal experience but on data original distribution. In the article, ''Enhanced dominant sets clustering by cluster expansion,'' to deal with the problem of the majority of existing algorithms depending on carefully tuned parameters to obtain satisfactory results, Hou and Zhang reduced the dependence on parameters on the basis of the dominant sets algorithm.

Among the accepted articles in this Special Section, five of them focused on the problem of CPS-oriented robust control and fault-tolerant control. The article, ''Blind source separation method for bearing vibration signals'' by He *et al*., addressed the problem of inaccurate estimation of the mixing matrix owing to noise and the choice of clustering method. In this article, the proposed algorithm was based on the modified k-means clustering algorithm and the Laplace potential function (LPH). In another article, ''Simultaneous robust, decoupled output feedback control for multivariate industrial systems,'' by Li *et al*., a simultaneous robust, decoupled output feedback control approach for multivariate industrial processes with parameter uncertainties was proposed. Yan *et al*., addressed a control problem for a group of unmanned underwater vehicles (UUVs) by tracking a maneuvering target with varying velocity and time delays in ''Coordinated target tracking strategy for multiple unmanned underwater vehicles with time delays.'' In the article, ''Effectiveness proving and control of platoon-based vehicular cyber-physical systems,'' Wu *et al*., proposed a timed Petri Nets model to delineate the behavior of platoons at an isolated intersection.

Hu *et al*., introduced the structural characteristics of a 6-D force sensor based on an E-type membrane, analyzed the calibration results of each bridge, and determined the coupling relationship between bridges of a sensor in the article, ''Decoupling analysis of a six-dimensional force sensor bridge fault.''

The problem of a unified framework for CPS formulation and analysis also draws some researchers' attention. In the article, ''Fault diagnosis based on belief rule base with considering attribute correlation,'' Feng *et al*., proposed a new BRB model with considering attribute correlation (BRB-c). In another article, ''Data mining and analytics in the process industry: The role of machine learning,'' Ge *et al*., provide a review on existing data mining and analytics applications in the process industry over the past several decades.

Challenges and techniques for potential industrial and domestic applications are also addressed in the Special Section. Zhang *et al*., in ''Three-dimensional underwater path planning based on modified wolf pack algorithm,'' aimed to overcome the shortcomings of wolf pack algorithm, such as a slow rate of convergence and low convergence precision, by improving the three intelligent behaviors of wolf pack algorithm. A double-layer BRB model was proposed to predict the health state of a complex electromechanical system in the article, ''A double layer BRB model for health prognostics in complex electromechanical system,'' by Yin *et al*. During this process, the infinite irrelevance method was utilized for feature selection in reducing the scale of the BRB model.

Han *et al*., in ''Data-based predictive control for wastewater treatment process,'' proposed a data-based predictive control (DPC) strategy, based on the available sensing measurements, to control the dissolved oxygen (DO) concentration in Wastewater treatment process (WWTP). Experimental results demonstrated that the proposed DPC performed better than some existing methods. Zhu *et al*., presented a novel nonlinear control approach for a medium-density fiberboard continuous hot pressing hydraulic system in the article, ''Adaptive neural network saturated control for MDF continuous hot pressing hydraulic system with uncertainties.'' In this article, uncertainties, disturbances, and input saturation are explicitly taken into account. In the meantime, Chen and Meng investigated an adaptive pesticide spraying system according to the plants' height

in the article, ''Development and performance test of a height-adaptive pesticide spraying system.'' In this article, both the depth and color data of the figure are obtained and analyzed, and the open or closed state of the spraying system is optimized for different plants with different height.

This Special Section on data-driven monitoring, fault diagnosis and control of cyber-physical systems is crucial and we hope useful for readers. The Guest Editors would like to thank the Editor-in-Chief and Managing Editor for giving us the opportunity to lead this Special Section on ''Data-driven monitoring, fault diagnosis and control of cyber-physical systems,'' and their valuable guidance and encouragement. Also, we gratefully thank all the authors who submitted articles for consideration to the Special Section, as well as the reviewers for their time and detailed reviews. Finally, we sincerely hope the readers can all benefit from this Special Section.

SHEN YIN, *Guest Editor*
Harbin Institute of Technology
Harbin 150001, China

OKYAY KAYNAK, *Guest Editor*
Department of Electrical and Electronics Engineering
Bogazici University
34342 Istanbul, Turkey

HAMID REZA KARIMI, *Guest Editor*
Department of Mechanical Engineering
Politecnico di Milano
20156 Milan, Italy

SHEN YIN (Senior Member, IEEE) received the B.E. degree in automation from the Harbin Institute of Technology, Harbin, China, in 2004, the M.Sc. degree in control and information systems and the Ph.D. degree in electrical engineering and information technology from the University of Duisburg–Essen, Duisburg, Germany, in 2007 and 2012, respectively. He is currently a Professor with the School of Astronautics, Harbin Institute of Technology. His research interests include data-driven control and diagnosis, machine learning and artificial intelligence, safety, reliability and security of complicated systems, and autonomous cyber-physical systems.

OKYAY KAYNAK (Fellow, IEEE) received the Ph.D. degree from the Department of Electronic and Electrical Engineering, University of Birmingham, Birmingham, U.K., in 1972. From 1972 to 1979, he held various positions in industry. In 1979, he joined the Department of Electrical and Electronics Engineering, Bogazici University, Istanbul, Turkey, where he is currently a Full Professor. He is currently the UNESCO Chair on Mechatronics and the Director of the Mechatronics Research and Application Center. His research interests include intelligent control, advanced motion control, soft computing, and mechatronics. He has authored three books, edited five books, and has authored or coauthored more than 400 articles that have appeared in various journals, books, and conference proceedings. He is the Editor-in-Chief of the IEEE/ASME TRANSACTIONS ON MECHATRONICS.

HAMID REZA KARIMI received the B.Sc. degree (Hons.) in power systems from the Sharif University of Technology, Tehran, Iran, in 1998, and the M.Sc. and Ph.D. (Hons.) degrees in control systems engineering from the University of Tehran, Tehran, in 2001 and 2005, respectively. Since 2016, he has been an Associate Professor of applied mechanics with the Department of Mechanical Engineering, Politecnico di Milano, Milan, Italy. His current research interests include control systems and mechatronics with applications to automotive control systems and wind energy. He is also a member of the IEEE Technical Committee on Systems with Uncertainty, the Committee on Industrial Cyber-Physical Systems, the IFAC Technical Committee on Mechatronic Systems, the Committee on Robust Control, and the Committee on Automotive Control. As recognition for his significant contributions and success to both teaching and research, he has been presented several awards, including the Alexander-von-Humboldt Research Fellowship Award, the JSPS Research Award, the DAAD Research Award, the August-Wilhelm-Scheer Award, and the 2016 and 2017 Web of Science Highly Cited Researcher in Engineering. He is currently the Editor-in-Chief of the *Journal of Cyber-Physical Systems* (Taylor & Francis), the *Journal of Machines* (MDPI Switzerland), and the *Journal of Designs* (MDPI Switzerland). He is an Editorial Board Member of some international journals, such as the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, the IEEE TRANSACTIONS ON CIRCUIT AND SYSTEMS—I: REGULAR PAPERS, the IEEE/ASME TRANSACTIONS ON MECHATRONICS, the IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS: SYSTEMS, *Information Sciences*, IEEE ACCESS, *IFAC-Mechatronics*, *Neurocomputing*, the *Asian Journal of Control*, the *Journal of The Franklin Institute*, the *International Journal of Control, Automation, and Systems*, the *International Journal of Fuzzy Systems*, the *International Journal of e-Navigation and Maritime Economy*, and the *Journal of Systems and Control Engineering*.