# Data Driven Methods For Fault Detection And Diagnosis In Chemical Processes Advances In Industrial Control

Early and accurate fault detection and diagnosis for modern chemical plants can minimise downtime, increase the safety of plant operations, and reduce manufacturing costs. The process-monitoring techniques that have been most effective in practice are based on models constructed almost entirely from process data. The goal of the book is to present the theoretical background and practical techniques for data-driven process monitoring. Process-monitoring techniques presented include: Principal component analysis; Fisher discriminant analysis; Partial least squares; Canonical variate analysis. The text demonstrates the application of all of the data-driven process monitoring techniques to the Tennessee Eastman plant simulator - demonstrating the strengths and weaknesses of each approach in detail. This aids the reader in selecting the right method for his process application. Plant simulator and homework problems in which students apply the process-monitoring techniques to a nontrivial simulated process, and can compare their performance with that obtained in the case studies in the text are included. A number of additional homework problems encourage the reader to implement and obtain a deeper understanding of the techniques. The reader will obtain a background in data-driven techniques for fault detection and diagnosis, including the ability to implement the techniques and to know how to select the right technique for a particular application.

Zhiwen Chen aims to develop advanced fault detection (FD) methods for the monitoring of industrial processes. With the ever increasing demands on reliability and safety in industrial processes, fault detection has become an important issue. Although the model-based fault detection theory has been well studied in the past decades, its applications are limited to large-scale industrial processes because it is difficult to build accurate models. Furthermore, motivated by the limitations of existing data-driven FD methods, novel canonical correlation analysis (CCA) and projection-based methods are proposed from the perspectives of process input and output data, less engineering effort and wide application scope. For performance evaluation of FD methods, a new index is also developed.

The safe and reliable operation of technical systems is of great significance for the protection of human life and health, the environment, and of the vested economic value. The correct functioning of those systems has a profound impact also on production cost and product quality. The early detection of faults is critical in avoiding performance degradation and damage to the machinery or human life. Accurate diagnosis then helps to make the right decisions on emergency actions and repairs. Fault detection and diagnosis (FDD) has developed into a major area of research, at the intersection of systems and control engineering, artificial intelligence, applied mathematics and statistics, and such application fields as chemical, electrical, mechanical and aerospace engineering. IFAC has recognized the significance of FDD by launching a triennial symposium series dedicated to the subject. The SAFEPROCESS Symposium is organized every three years since the first symposium held in Baden-Baden in 1991. SAFEPROCESS 2006, the 6th IFAC Symposium on Fault Detection, Supervision and Safety of Technical Processes was held in Beijing, PR China. The program included three plenary papers, two semi-plenary papers, two industrial talks by internationally recognized experts and 258 regular papers, which have been selected out of a total of 387 regular and invited papers submitted. * Discusses the developments and future challenges in all aspects of fault diagnosis and fault tolerant control * 8 invited and 36 contributed sessions included with a special session on the demonstration of process monitoring and diagnostic software tools

Residential and commercial buildings are responsible for more than 40% of the primary energy consumption in the United States. Energy wastes are estimated to reach 15% to 30% of total energy consumption due to malfunctioning sensors, components, and control systems, as well as degrading components in Heating, Ventilation, Air-conditioning (HVAC) systems and lighting systems in commercial buildings in the U.S. Studies have demonstrated that a large energy saving can be achieved by automated fault detection and diagnosis (AFDD) followed by corrections. Field studies have shown that, AFDD tools can help to reach energy savings by 5-30% from different systems such as HVAC systems, lighting systems, and refrigeration systems. At the same time, the deployment of AFDD tools can also significantly improve indoor air quality, reduce peak demand, and lower pollution. In buildings, many components or equipment are closely coupled in a HVAC system. Because of the coupling, a fault happening in one component might propagate and affect other components or subsystems. In this study, a whole building fault (WBF) is defined as a fault that occurs in one component or equipment but causes fault impacts (abnormalities) on other components and subsystems, or causes significant impacts on energy consumption and/or indoor air quality. Over the past decades, extensive research have been conducted on the development of component AFDD methods and tools. However, whole building AFDD methods, which can detect and diagnose a WBF, have not been well studied. Existing component level AFDD solutions often fail to detect a WBF or generate a high false alarm rate. Isolating a WBF is also very challenging by using component level AFDD solutions. Even with the extensive research, cost-effectiveness and scalability of existing AFDD methods are still not satisfactory. Therefore, the focus of this research is to develop cost-effective and scalable solutions for WBF AFDD. This research attempts to integrate data-driven methods with expert knowledge/rules to overcome the above-mentioned challenges. A suite of WBF AFDD methods have hence been developed, which include: 1) a weather and schedule based pattern matching method and feature based Principal Component Analysis (WPM-FPCA) method for whole building fault detection. The developed WPM-FPCA method successfully overcome the challenges such as the generation of accurate and dynamic baseline and data dimensionality reduction. And 2) a data-driven and expert knowledge/rule based method using both Bayesian Network (BN) and WPM for WBF diagnosis. The developed WPM-BN method includes a two-layer BN structure model and BN parameter model which are either learned from baseline data or developed from expert knowledge. Various WBFs have been artificially implemented in a real demo building. Building operation data which include baseline data, data that contain naturally-occurred faults and artificially implemented faults are collected and analyzed. Using the collected real building data, the developed methods are evaluated. The evaluation demonstrates the efficacy of the developed methods to detect and diagnose a WBF, as well as their implementation cost-effectiveness.

This thesis develops a systematic, data-based dynamic modeling framework for industrial processes in keeping with the slowness principle. Using said framework as a point of departure, it then proposes novel strategies for dealing with control monitoring and quality prediction problems in industrial production contexts. The thesis reveals the slowly varying nature of industrial production processes under feedback control, and integrates it with process data analytics to offer powerful prior knowledge that gives rise to statistical methods tailored to industrial data. It addresses several issues of immediate interest in industrial practice, including process monitoring, control performance assessment and diagnosis, monitoring system design, and product quality prediction. In particular, it proposes a holistic and pragmatic design framework for industrial monitoring systems, which delivers effective elimination of false alarms, as well as intelligent self-running by fully utilizing the information underlying the data. One of the strengths of this thesis is its integration of insights from statistics, machine learning, control theory and engineering to provide a new scheme for industrial process modeling in the era of big data.

The two-volume set LNAI 6922 and LNAI 6923 constitutes the refereed proceedings of the Third International Conference on Computational Collective Intelligence, ICCCI 2011, held in Gdynia, Poland, in September 2011. The 112 papers in this two volume set presented together with 3 keynote speeches were carefully reviewed and selected from 300 submissions. The papers are organized in topical sections on knowledge management, machine learning and applications, autonomous and collective decision-making, collective computations and optimization, Web services and semantic Web, social networks and computational swarm intelligence and applications.

The major objective of this book is to introduce advanced design and (online) optimization methods for fault diagnosis and fault-tolerant control from different aspects. Under the aspect of system types, fault diagnosis and fault-tolerant issues are dealt with for linear time-invariant and time-varying systems as well as for nonlinear and distributed (including networked) systems. From the methodological point of view, both model-based and data-driven schemes are investigated.To allow for a self-contained study and enable an easy implementation in real applications, the necessary knowledge as well as tools in mathematics and control theory are included in this book. The main results with the fault diagnosis and fault-tolerant schemes are presented in form of algorithms and demonstrated by means of benchmark case studies. The intended audience of this book are process and control engineers, engineering students and researchers with control engineering background.

This book examines recent methods for data-driven fault diagnosis of multimode continuous processes. It formalizes, generalizes, and systematically presents the main concepts, and approaches required to design fault diagnosis methods for multimode continuous processes. The book provides both theoretical and practical tools to help readers address the fault diagnosis problem by drawing data-driven methods from at least three different areas: statistics, unsupervised, and supervised learning.

This book offers an overview of current and recent methods for the analysis of the nonstationary processes, focusing on cyclostationary systems that are ubiquitous in various application fields. Based on the 13th Workshop on Nonstationary Systems and Their Applications, held on February 3-5, 2020, in Grodek nad Dunajcem, Poland, the book merges theoretical contributions describing new statistical and intelligent methods for analyzing nonstationary processes, and applied works showing how the proposed methods can be implemented in practice and do perform in real-world case studies. A significant part of the book is dedicated to nonstationary systems applications, with a special emphasis on those in condition monitoring.

This book introduces condition-based maintenance (CBM)/data-driven prognostics and health management (PHM) in detail, first explaining the PHM design approach from a systems engineering perspective, then summarizing and elaborating on the data-driven methodology for feature construction, as well as feature-based fault diagnosis and prognosis. The book includes a wealth of illustrations and tables to help explain the algorithms, as well as practical examples showing how to use this tool to solve situations for which analytic solutions are poorly suited. It equips readers to apply the concepts discussed in order to analyze and solve a variety of problems in PHM system design, feature construction, fault diagnosis and prognosis.

This utterly comprehensive work is thought to be the first to integrate the literature on the physics of the failure of complex systems such as hospitals, banks and transport networks. It has chapters on particular aspects of maintenance written by internationally-renowned researchers and practitioners. This book will interest maintenance engineers and managers in industry as well as researchers and graduate students in maintenance, industrial engineering and applied mathematics.

Fault Diagnosis of Dynamic Systems provides readers with a glimpse into the fundamental issues and techniques of fault diagnosis used by Automatic Control (FDI) and Artificial Intelligence (DX) research communities. The book reviews the standard techniques and approaches widely used in both communities. It also contains benchmark examples and case studies that demonstrate how the same problem can be solved using the presented approaches. The book also introduces advanced fault diagnosis approaches that are currently still being researched, including methods for non-linear, hybrid, discrete-event and software/business systems, as well as, an introduction to prognosis. Fault Diagnosis of Dynamic Systems is valuable source of information for researchers and engineers starting to work on fault diagnosis and willing to have a reference guide on the main concepts and standard approaches on fault diagnosis. Readers with experience on one of the two main communities will also find it useful to learn the fundamental concepts of the other community and the synergies between them. The book is also open to researchers or academics who are already familiar with the standard approaches, since they will find a collection of advanced approaches with more specific and advanced topics or with application to different domains. Finally, engineers and researchers looking for transferable fault diagnosis methods will also find useful insights in the book.

Aiming at improving the reliability and durability of Polymer Electrolyte Membrane Fuel Cell (PEMFC) systems and promote the commercialization of fuel cell technologies, this thesis work is dedicated to the fault diagnosis study for PEMFC systems. Data-driven fault diagnosis is the main focus in this thesis. As a main branch of data-driven fault diagnosis, the methods based on pattern classification techniques are firstly studied. Taking individual fuel cell voltages as original diagnosis variables, several representative methodologies are investigated and compared from the perspective of online implementation.Specific to the defects of conventional classification based diagnosis methods, a novel diagnosis strategy is proposed. A new classifier named Sphere-Shaped Multi-class Support Vector Machine (SSM-SVM) and modified diagnostic rules are utilized to realize the novel fault recognition. While an incremental learning method is extended to achieve the online adaptation.Apart from the classification based diagnosis approach, a so-called partial model-based data-driven approach is introduced to handle PEMFC diagnosis in dynamic processes. With the aid of a subspace identification method (SIM), the model-based residual generation is designed directly from the normal and dynamic operating data. Then, fault detection and isolation are further realized by evaluating the generated residuals.The proposed diagnosis strategies have been verified using the experimental data which cover a set of representative faults and different PEMFC stacks. The preliminary online implementation results with an embedded system are also supplied.

Fault diagnosis is useful for technicians to detect, isolate, identify faults, and troubleshoot. Bayesian network (BN) is a probabilistic graphical model that effectively deals with various uncertainty problems. This model is increasingly utilized in fault diagnosis. This unique compendium presents bibliographical review on the use of BNs in fault diagnosis in the last decades with focus on engineering systems. Subsequently, eleven important issues in BN-based fault diagnosis

methodology, such as BN structure modeling, BN parameter modeling, BN inference, fault identification, validation, and verification are discussed in various cases. Researchers, professionals, academics and graduate students will better understand the theory and application, and benefit those who are keen to develop real BN-based fault diagnosis system.
This unique text/reference describes in detail the latest advances in unsupervised process monitoring and fault diagnosis with machine learning methods. Abundant case studies throughout the text demonstrate the efficacy of each method in real-world settings. The broad coverage examines such cutting-edge topics as the use of information theory to enhance unsupervised learning in tree-based methods, the extension of kernel methods to multiple kernel learning for feature extraction from data, and the incremental training of multilayer perceptrons to construct deep architectures for enhanced data projections. Topics and features: discusses machine learning frameworks based on artificial neural networks, statistical learning theory and kernel-based methods, and tree-based methods; examines the application of machine learning to steady state and dynamic operations, with a focus on unsupervised learning; describes the use of spectral methods in process fault diagnosis.

Data-driven Design of Fault Diagnosis and Fault-tolerant Control Systems presents basic statistical process monitoring, fault diagnosis, and control methods and introduces advanced data-driven schemes for the design of fault diagnosis and fault-tolerant control systems catering to the needs of dynamic industrial processes. With ever increasing demands for reliability, availability and safety in technical processes and assets, process monitoring and fault-tolerance have become important issues surrounding the design of automatic control systems. This text shows the reader how, thanks to the rapid development of information technology, key techniques of data-driven and statistical process monitoring and control can now become widely used in industrial practice to address these issues. To allow for self-contained study and facilitate implementation in real applications, important mathematical and control theoretical knowledge and tools are included in this book. Major schemes are presented in algorithm form and demonstrated on industrial case systems. Data-driven Design of Fault Diagnosis and Fault-tolerant Control Systems will be of interest to process and control engineers, engineering students and researchers with a control engineering background.

Control systems at production plants consist of a large number of process variables. When detecting abnormal behavior, these variables generate an alarm. Due to the interconnection of the plant's devices the fault can lead to an alarm flood. This again hides the original location of the causing device. In this work several data-driven approaches for root cause localization are proposed, compared and combined. All methods analyze disturbed process data for backtracking the propagation path. This work was published by Saint Philip Street Press pursuant to a Creative Commons license permitting commercial use. All rights not granted by the work's license are retained by the author or authors.

This book presents recent advances in fault diagnosis strategies for complex dynamic systems. Its impetus derives from the need for an overview of the challenges of the fault diagnosis technique, especially for those demanding systems that require reliability, availability, maintainability and safety to ensure efficient operations. Moreover, the need for a high degree of tolerance with respect to possible faults represents a further key point, primarily for complex systems, as modeling and control are inherently challenging, and maintenance is both expensive and safety-critical. Diagnosis and Fault-tolerant Control 1 also presents and compares different diagnosis schemes using established case studies that are widely used in related literature. The main features of this book regard the analysis, design and implementation of proper solutions for the problems of fault diagnosis in safety critical systems. The design of the considered solutions involves robust data-driven, model-based approaches.

This book constitutes selected papers from the Second International Workshop on IoT Streams for Data-Driven Predictive Maintenance, IoT Streams 2020, and First International Workshop on IoT, Edge, and Mobile for Embedded Machine Learning, ITEM 2020, co-located with ECML/PKDD 2020 and held in September 2020. Due to the COVID-19 pandemic the workshops were held online. The 21 full papers and 3 short papers presented in this volume were thoroughly reviewed and selected from 35 submissions and are organized according to the workshops and their topics: IoT Streams 2020: Stream Learning; Feature Learning; ITEM 2020: Unsupervised Machine Learning; Hardware; Methods; Quantization.

In the current age of information explosion, newly invented technological sensors and software are now tightly integrated with our everyday lives. Many sensor processing algorithms have incorporated some forms of computational intelligence as part of their core framework in problem solving. These algorithms have the capacity to generalize and discover knowledge for themselves and learn new information whenever unseen data are captured. The primary aim of sensor processing is to develop techniques to interpret, understand, and act on information contained in the data. The interest of this book is in developing intelligent signal processing in order to pave the way for smart sensors. This involves mathematical advancement of nonlinear signal processing theory and its applications that extend far beyond traditional techniques. It bridges the boundary between theory and application, developing novel theoretically inspired methodologies targeting both longstanding and emergent signal processing applications. The topic ranges from phishing detection to integration of terrestrial laser scanning, and from fault diagnosis to bio-inspiring filtering. The book will appeal to established practitioners, along with researchers and students in the emerging field of smart sensors processing.

This book is a comprehensive collection of chapters focusing on the core areas of computing and their further applications in the real world. Each chapter is a paper presented at the Computing Conference 2021 held on 15-16 July 2021. Computing 2021 attracted a total of 638 submissions which underwent a double-blind peer review process. Of those 638 submissions, 235 submissions have been selected to be included in this book. The goal of this conference is to give a platform to researchers with fundamental contributions and to be a premier venue for academic and industry practitioners to share new ideas and development experiences. We hope that readers find this volume interesting and valuable as it provides the state-of-the-art intelligent methods and techniques for solving real-world problems. We also expect that the conference and its publications is a trigger for further related research and technology improvements in this important subject. .

This book assesses the potential of data-driven methods in industrial process monitoring engineering. The process modeling, fault detection, classification, isolation, and reasoning are studied in detail. These methods can be used to improve the safety and reliability of industrial processes. Fault diagnosis, including fault detection and reasoning, has attracted engineers and scientists from various fields such as control, machinery, mathematics, and automation engineering. Combining the diagnosis algorithms and application cases, this book establishes a basic framework for this topic and implements various statistical analysis methods for process monitoring. This book is intended for senior undergraduate and graduate students who are interested in fault diagnosis technology, researchers investigating automation and industrial

security, professional practitioners and engineers working on engineering modeling and data processing applications.
To plan, build, monitor, maintain, and dispose of products and assets properly, maintenance and safety requirements must be implemented and followed. A lack of maintenance and safety protocols leads to accidents and environmental disasters as well as unexpected downtime that costs businesses money and time. With the arrival of the Fourth Industrial Revolution and evolving technological tools, it is imperative that safety and maintenance practices be reexamined. Applications and Challenges of Maintenance and Safety Engineering in Industry 4.0 is a collection of innovative research that addresses safety and design for maintenance and reducing the factors that influence and degrade human performance and that provides technological advancements and emergent technologies that reduce the dependence on operator capabilities. Highlighting a wide range of topics including management analytics, internet of things (IoT), and maintenance, this book is ideally designed for engineers, software designers, technology developers, managers, safety officials, researchers, academicians, and students.
Modern industrial processes are becoming more complex, and consequently monitoring them has become a challenging task. Fault Detection and Diagnosis (F01) as a key element of process monitoring, needs to be investigated because of its essential role in decision making processes. Among available F01 methods, data driven approaches are currently receiving increasing attention because of their relative simplicity in implementation. Regardless of F01 types, one of the main traits of reliable F01 systems is their ability of being updated while new conditions that were not considered at their initial training appear in the process. These new conditions would emerge either gradually or abruptly, but they have the same level of importance as in both cases they lead to F01 poor performance. For addressing updating tasks, some methods have been proposed, but mainly not in research area of chemical engineering. They could be categorized to those that are dedicated to managing Concept Drift (CD) (that appear gradually), and those that deal with novel classes (that appear abruptly). The available methods, mainly, in addition to the lack of clear strategies for updating, suffer from performance weaknesses and inefficient required time of training, as reported. Accordingly, this thesis is mainly dedicated to data driven F01 updating in chemical processes. The proposed schemes for handling novel classes of faults are based on unsupervised methods, while for coping with CD both supervised and unsupervised updating frameworks have been investigated. Furthermore, for enhancing the functionality of F01 systems, some major methods of data processing, including imputation of missing values, feature selection, and feature extension have been investigated. The suggested algorithms and frameworks for F01 updating have been evaluated through different benchmarks and scenarios. As a part of the results, the suggested algorithms for supervised handling CD surpass the performance of the traditional incremental learning in regard to MGM score (defined dimensionless score based on weighted F1 score and training time) even up to 50% improvement. This improvement is achieved by proposed algorithms that detect and forget redundant information as well as properly adjusting the data window for timely updating and retraining the fault detection system. Moreover, the proposed unsupervised F01 updating framework for dealing with novel faults in static and dynamic process conditions achieves up to 90% in terms of the NPP score (defined dimensionless score based on number of the correct predicted class of samples). This result relies on an innovative framework that is able to assign samples either to new classes or to available classes by exploiting one class classification techniques and clustering approaches.
In many industrial applications early detection and diagnosis of abnormal behavior of the plant is of great importance. During the last decades, the complexity of process plants has been drastically increased, which imposes great challenges in development of model-based monitoring approaches and it sometimes becomes unrealistic for modern large-scale processes. The main objective of Adel Haghani Abandan Sari is to study efficient fault diagnosis techniques for complex industrial systems using process historical data and considering the nonlinear behavior of the process. To this end, different methods are presented to solve the fault diagnosis problem based on the overall behavior of the process and its dynamics. Moreover, a novel technique is proposed for fault isolation and determination of the root-cause of the faults in the system, based on the fault impacts on the process measurements.
This book provides a complete picture of several decision support tools for predictive maintenance. These include embedding early anomaly/fault detection, diagnosis and reasoning, remaining useful life prediction (fault prognostics), quality prediction and self-reaction, as well as optimization, control and self-healing techniques. It shows recent applications of these techniques within various types of industrial (production/utilities/equipment/plants/smart devices, etc.) systems addressing several challenges in Industry 4.0 and different tasks dealing with Big Data Streams, Internet of Things, specific infrastructures and tools, high system dynamics and non-stationary environments . Applications discussed include production and manufacturing systems, renewable energy production and management, maritime systems, power plants and turbines, conditioning systems, compressor valves, induction motors, flight simulators, railway infrastructures, mobile robots, cyber security and Internet of Things. The contributors go beyond state of the art by placing a specific focus on dynamic systems, where it is of utmost importance to update system and maintenance models on the fly to maintain their predictive power.
The main objective of Data-Driven and Model-Based Methods for Fault Detection and Diagnosis is to develop techniques that improve the quality of fault detection and then utilize these developed techniques to enhance monitoring various chemical and environmental processes. The book provides both the theoretical framework and technical solutions. It starts with reviewing relevant literature, proceeds with a detailed description of developed methodologies, followed by a discussion of the results of developed methodologies, and ends with major conclusions reached from the analysis of simulation and experimental studies. The book is an indispensable resource for researchers in academia and industry and practitioners working in chemical and environmental engineering to do their work safely. Outlines latent variable based hypothesis testing fault detection techniques to enhance monitoring processes represented by linear or nonlinear input-space models (such as PCA) or input-output models (such as PLS) Explains multiscale latent variable based hypothesis testing fault detection techniques using multiscale representation to help deal with uncertainty in the data and minimize its effect on fault detection Includes interval PCA (IPCA) and interval PLS (IPLS) fault detection methods to enhance the quality of fault detection Provides model-based detection techniques for improvement of monitoring processes using state estimation-based fault detection approaches Demonstrates the effectiveness of the proposed strategies by conducting simulation and experimental studies on synthetic data
Early and accurate fault detection and diagnosis for modern chemical plants can minimize downtime, increase the safety of plant operations, and reduce manufacturing costs. This book presents the theoretical background and practical techniques for data-driven process monitoring. It demonstrates the application of all the data-driven process monitoring techniques to the Tennessee Eastman plant simulator, and looks at the strengths and weaknesses of each approach in detail. A plant simulator and problems allow readers to apply process monitoring techniques.