Advances in intelligent computing for diagnostics, prognostics, and system health management

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2 authors:

Chuan Li
Chongqing Technology and Business University

José Valente de Oliveira
Universidade do Algarve

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Guest Editorial

Advances in intelligent computing for diagnostics, prognostics, and system health management

Chuan Li[a,*] and José Valente de Oliveira[b,*]
[a]*National Research Base of Intelligent Manufacturing Service, Chongqing Technology and Business University, Chongqing, China*
[b]*CEOT, Universidade do Algarve, Faro, Portugal*

This special issue of the Journal of Intelligent & Fuzzy Systems on intelligent computing for diagnostics, prognostics, and system health management is edited from a selection of papers which were originally presented at SDPC 2017 – the 2017 International Conference on Sensing, Diagnosis, and Control, held in Shanghai, China, in August 2017. The guest editors have accepted 41 papers with the special issue.

By diagnosis, prognostics and system health management we mean a set of activities including: fault detection, fault classification, fault prognosis, and system modeling. Informally, fault detection refers to the real-time signal processing required to know whether or not a given system is in its healthy normal operating state. Fault classification refers to determination of the type of fault an unhealthy system is suffering from and is a pattern recognition task. Fault prognosis refers to the forecast of the remaining useful life of a system and is based on dynamic modeling. In general, these activities require a sequence of operations such as data acquisition and conditioning, feature extraction, feature selection, and a final detection/classification/forecast stage. Data acquisition can resort to different types of sensors. Features are extracted from the acquired signals. Time, frequency, and time-frequency features being typically computed.

In this special issue an attempt was made to include contributions in all the above activities in a diverse range of real-world applications. The applications range from batteries and bearings to gearboxes and pneumatic actuators in aircraft landing trains, passing through water pipe failure analysis and air particulate prediction. For this, application tailored intelligent and machine learning techniques including clustering, deep and extreme learning, sparse coding, support vector regression and classification and optimization algorithms are proposed.

To provide the reader with some orientation on this issue, the contributions are tentatively organized according to the usual data activity pipeline in fault diagnosis and prognosis, i.e., we start by the contributions on feature extraction, selection and fusion, followed by the contributions on fault detection, classification, and prognosis. Closely related with the last topic is modelling and forecasting, whose papers constitute the last group of contributions.

The work of J. Chen et al. [1] proposes the employment of image processing techniques, such as bi-spectrum and histogram of oriented gradient,

*Corresponding authors. Chuan Li, National Research Base of Intelligent Manufacturing Service, Chongqing Technology and Business University, Chongqing 400067, China. E-mail: chuanli@21cn.com and José Valente de Oliveira, CEOT, Universidade do Algarve, Faro, Portugal. E-mail: jvo@ualg.pt.

for automatic feature extraction in fault diagnosis of rotating machinery. The work of Su et al. [2] presents a new manifold learning framework for machinery fault diagnosis. It uses unsupervised manifold learning for signal denoising, followed by supervised manifold learning to feature extraction. A most relevant contribution in feature extraction is the work of D. Wang et al. [3] where the concept of blind fault component separation of low-frequency periodic vibration components from high-frequency random repetitive transients is proposed and used to enhance the performance of ensemble empirical mode decomposition for extracting features in an industrial railway axle bearing fault diagnosis.

The contributions of Z. Chen and Z. Li [4]; Peña et al. [5]; Sánchez et al. [6]; Xie et al. [7]; Jin et al. [8], and Luo et al. [9] deal with feature selection. Z. Chen and Z. Li propose a denoising deep autoencoder for feature selection in fault diagnosis of rotating machinery. Peña et al. propose a framework for feature engineering in the context of clustering which is based on ANOVA and Tukey's test for feature ranking. Sánchez et al. exploit random forests for featuring ranking in multi-fault diagnosis of rotating machinery. Criteria such as reliefF, chi square, or information gain are considered in their study. Xie et al. developed a deep believe network to the problem of daily forecast of particulate matter concentration. Jin et al. investigate the informative frequency band selection process in rotating machinery fault detection from the point of view of patter recognition. The spectrum of the acquired signal is divided in bands, features are computed for each band and the band with highest accuracy in a cross-validation setup is selected as the most informative. Another interesting contribution in feature selection is the work of Luo et al. where an orthogonal semi-supervised linear local tangent space alignment is proposed for such end.

Feature fusion is the main subject of the contributions of Jiang et al. [10] and X. Li et al. [11] In the paper of Jiang et al. a deep belief network is exploited as a feature fusion method for bearings diagnosis. The work of X. Li et al. reports the development of a fuzzy feature fusion and multimodal regression method for obtaining a degradation index for mechanical components. Parameter estimation resorts to an extreme learning machine.

The work of B. Wang et al. [12] and J. Shi et al. [13] focuses on fault detection. B. Wang and colleagues presents an innovative hardware implementation of an online anomaly detection system for an unmanned aerial vehicle. J. Shi et al. present a new instantaneous frequency estimation method based on the dual pre-IF integration strategy, from which bearing fault diagnosis can be done by multiple-demodulation.

Fault classification is investigated by C. Li et al. [14]; Pacheco et al. [15]; L. Duan et al. [16]; Medina et al. [17]; X. Wang et al. [18]; K. Liu et al. [19]; J. Meng et al. [20]; Sun et al. [21]; and Y. Liao et al. [22] In the work of C. Li et al. four representative fuzzy clustering algorithms (FCM, FCMFP, GK, and FN-DBSCAN) are compared for unsupervised fault classification under realistic experimental realistic conditions. Pacheco et al. propose a semi-supervised framework for fault diagnoses resorting to idea of clustering and classification. L. Duan et al. present a model based domain adaptation for the fault diagnosis of reciprocating compressor under varying working conditions. Medina et al. propose a method for gear fault diagnosis based on a spare representation that resorts to over completed dictionaries synthetized from vibration signals. X. Wang et al. describe an application of a deep believe networks to the fault diagnosis of planetary gearbox aiming at reducing the influence of the load. K. Liu et al. developed a fault diagnosis and location of an aircraft landing gear hydraulic retraction system, based on a denoising deep auto-encode and a support vector machine. In the work of J. Meng et al. recurrent neural networks and extreme learning are used for gear fault classification. Sun et al. exploit the crow search algorithm in condition monitoring of a boost converter. In the work of Y. Liao et al. a variant of the particle swarm optimization algorithm is used for simultaneously optimization of the structure and parameters of a neural network for gearbox fault diagnosis.

Prognosis is the main concern in the papers of B. Wang et al. [23]; H. Pei et al. [24]; F. Sun et al. [25]; Y. Wang et al. [26]; Z. Cheng et al. [27]; G. Tang et al. [28]; S. Yang et al. [29]; and X. Li et al. [30] The paper of B. Wang et al. proposes to analyze the degradation condition for rolling bearings using fuzzy C-means and an improved pattern spectrum entropy as feature. The manuscript is completed with real world experimental data. The paper of H. Pei et al. presents a novel life prediction method for equipment considering the influence of imperfect maintenance activities on both the degradation level and the degradation rate. The manuscript of F. Sun et al. proposes a method for bivariate accelerated degradation testing which is based on Brownian motion and time-varying copula. The manuscript of Y. Wang et al. proposes a remaining useful life prediction method for rolling bearing prognosis based on both spare coding and sparse linear auto-regressive models. The paper of Z. Cheng et al. proposes a locally linear fusion regression for estimating the remaining useful life of rolling bearings. The manuscript of G. Tang et al. proposes a multivariate least square support vector machine with moving window over times slices for dealing with the time varying nature of the signals used for bearings fault diagnosis. S. Yang et al. work applies a mean-covariance decomposition method in a moving window to analyze the degradation of lithium Ion batteries. In the study of X. Li et al. canonicalvariate analysis, Cox proportional hazard and support vector regression are employed to identify fault related variables and predict remaining usable time of an industrial reciprocating compressor.

The last group of contributions are devoted to modeling and forecasting issues and include the works of J. Pang et al. [31]; Cabrera et al. [32]; X. Wang et al. [33]; J. Long et al. [34]; Y. Li et al. [35]; F. Shi et al. [36]; W. Song et al. [37]; W. Guo et al. [38]; Y. Zhang et al. [39]; D. Singh et al. [40]; and X. Tang et al. The J. Pang et al. manuscript presents an improved representation method for Satellite telemetry time series representation. The method is based on a series of characteristic (special) points. The series is then analyzed by hierarchical clustering. The most relevant contribution of Cabrera et al. encompasses a methodology for the dynamic system modelling resorting to reservoir computing, variational inference and deep learning. The manuscript of Xiaodan Wang et al. describes the application of an ensemble method, where diversity is obtained from different data views, for short-term wind seed forecasting. The input sequence is treated by variational model decomposition, and the forecast resorts to support vector regression. The manuscript of Jianyu Long et al. focuses on modeling methods for integrated determination of the charge batching and casting start time in steel plants. The work of Yong Li et al. proposes a pipeline comprehending multiscale analysis with stationary wavelet transform, partial least squares, and support vector regression for forecasting daily PM_{10} concentration, a widely discussed issue in environmental monitoring and protection. F. Shi et al. manuscript studies the application of five machine learning well-known methods (Multiple linear regression, random forests, artificial neural nets, support vector machines, and ensembles) in the prediction of water pipe failure performance. The W. Song et al. manuscript proposes a simulation model based fault diagnosis method for bearings. The simulation model resorts to the finite element method. In the W. Guo et al. paper the authors constructed a dynamic model for a two-stage planetary gearbox with a varying crack on the sun gear tooth root. After that, they used the model to generate and analyze vibration responses. In the work of Y. Zhang et al. a new method of unit testing based on the coverage selection approach using a decision inheritance tree is proposed. In the paper of D. Singh et al. the angle of attack of an aircraft is estimated indirectly via interval type-2 fuzzy sets and systems using data obtained from aircraft speed sensor, linear acceleration sensor and pitch angle sensor. X. Tang and colleagues investigate distance and similarity measures within the context of hesitant fuzzy sets. They propose a new axiomatization for distance measures of hesitant fuzzy sets and then develop novel distance measures for hesitant fuzzy sets.

As can be seen from the enclosed selection of papers intelligent computing techniques are playing a crucial role in system health management. It is apparent from this particular selection of papers that system health management can benefit significantly, in several of their main activities, from both intelligent and machine learning techniques. On the other hand, it is also clear that these methods are still growing in variety and depth. The guest editors are convinced that the reader will find these contributions worth reading and inviting further research on intelligent models, tools, and new paradigms.

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References

[1] J. Chen, D. Zhou, Y. Wang, Ho. Fu and M. Wang, Image feature extraction based on HOG and its application to fault diagnosis for rotating machinery, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[2] Z. Su, H. Xu, J. Luo, K. Zheng and Y. Zhang, Fault diagnosis method based on a new manifold learning framework, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[3] D. Wang, C. Yi and K. L. Tsui, Making EEMD more effective in extracting bearing fault features for intelligent bearing fault diagnosis by using blind fault component

separation, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[4] Z. Chen and Z. Li, Fault diagnosis method of rotating machinery based on stacked denoising autoencoder, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[5] M. Peña, M. Cerrada, X. Alvarez, D. Jadán, P. Lucero, M. Barragán, R. Guamán and R.-V. Sánchez, Feature engineering based on ANOVA and cluster validity assessment for fault diagnosis in bearings, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[6] R.-V. Sánchez, P. Lucero, R. E. Vásquez, M. Cerrada, J.-C. Macancel, D. Cabrera and F. Pacheco, Feature ranking for multi-fault diagnosis of rotating machinery by using random forest and KNN, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[7] J. Xie, X. Wang, Y. Liu and Y. Bai, Autoencoder-based deep belief regression network for air particulate matter concentration forecasting, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[8] Y. Jin, Z. Liu, D. Peng, J. Kang and J. Ding, Informative frequency band selection based on a new indicator: Accuracy rate, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[9] J. Luo, H. Xu, Z. Su, H. Xiao, K. Zheng and Y. Zhang, Fault diagnosis based on orthogonal semi-supervised LLTSA for feature extraction and Transductive SVM for fault identification, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[10] H. Jiang, H. Shao, X. Chen and J. Huang, A feature fusion deep belief network method for intelligent fault diagnosis of rotating machinery, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[11] X. Li, Y. Ren and X. Tan, Fuzzy feature fusion and multimodal degradation prognosis for mechanical components, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[12] B. Wang, Y. Chen, D. Liu and X. Peng, An embedded intelligent system for on-line anomaly detection of unmanned aerial vehicle, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[13] J. Shi, Z. Zhu, M. Liang, R. Ding and X. Jiang, Automatic instantaneous frequency order (IFO) extraction via integration strategy and multi-demodulation for bearing fault diagnosis under variable speed operation, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[14] C. Li, M. Cerrada, D. Cabrera, R. V. Sánchez, F. Pacheco, G. Ulutagay and J. Valente de Oliveira, A comparison of fuzzy clustering algorithms for bearing fault diagnosis, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[15] F. Pacheco, M. Cerrada, R.-V. Sánchez and D. Cabrera, A semi-supervised approach based on evolving clusters for discovering unknown abnormal condition patterns in gearboxes, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[16] L. Duan, X. Wang, M. Xie, Z. Yuan and J. Wang, Auxiliary-model-based domain adaptation for reciprocating compressor diagnosis under variable conditions, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[17] R. Medina, X. Alvarez, D. Jadan, J.-C. Macancela, R.-V. Sanchez and M. Cerrada, Gearbox fault classification using dictionary sparse based representations of vibration signals, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[18] X. Wang, Y. Qin and A. Zhang, An intelligent fault diagnosis approach for planetary gearboxes based on deep belief networks and uniformed features, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[19] K. Liu, Y. Feng and X. Xue, Fault diagnosis of hydraulic retraction system based on multi-source signals feature fusion and health assessment for the actuator, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[20] J. Meng, L. Zhao, F. Shen and R. Yan, Gear fault diagnosis based on recurrence network, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[21] Q. Sun, Y. Wang, Y. Jiang and L. Shao, Non-invasive condition monitoring for boost converter based on crow search algorithm, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[22] Y. Liao, L. Zhang and W. Li, Regrouping particle swarm optimization based variable neural network for gearbox fault diagnosis, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[23] B. Wang, W. Wang, M. Hou and X. Hu, Bearing performance degradation condition recognition based on a combination of improved pattern spectrum entropy and fuzzy C-means, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[24] H. Pei, X. Si, C. Hu, Z. Wang, D. Du and Z. Pang, A multi-stage wiener process-based prognostic model for equipment considering the influence of imperfect maintenance activities, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[25] F. Sun, N. Wang, Y. Cheng and X. Li, A time-varying copula-based prognostics method for bivariate accelerated degradation testing, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[26] Y. Wang, H. Li, J. Yang, D. Yao and S. He, Sparse coding based RUL prediction and its application on roller bearing prognostics, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[27] Z. Cheng and B. Cai, Predicting the remaining useful life of rolling element bearings using locally linear fusion regression, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[28] G. Tang, Y. Zhang and H. Wang, Multivariable LS-SVM with moving window over time slices for the prediction of bearing performance degradation, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[29] S. Yang, Z. Li and J. Guo, A mean-covariance decomposition method for battery capacity prognostics, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[30] X. Li, F. Duan, I. Bennett and D. Mba, Canonical variate analysis, probability approach and support vector regression for fault identification and failure time prediction, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[31] J. Pang, D. Liu, Y. Peng and X. Peng, Agglomerative hierarchical clustering of satellite telemetry series with improved time series representation, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[32] D. Cabrera, F. Sancho, M. Cerrada, R.-V. Sánchez and F. Tobar, Combining reservoir computing and variational inference for efficient one-class learning on dynamical systems, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[33] X. Wang, Q. Yu and Y. Yang, Short-term wind speed forecasting using variational mode decomposition and support vector regression, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[34] J. Long, Z. Sun, H. Chen, Y. Bai and Y. Hong, Variable neighborhood search for integrated determination of charge

batching and casting start time in steel plants, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[35] Y. Li and Y. Tao, Daily PM10 concentration forecasting based on multiscale fusion support vector regression, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[36] F. Shi, Y. Liu, Z. Liu and E. Li, Prediction of pipe performance with stacking ensemble learning based approaches, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[37] W. Song, J. Xiang and Y. Zhong, A simulation model based fault diagnosis method for bearings, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[38] W. Guo, C. Chen and N. Xiao, Dynamic vibration feature analyses for a two-stage planetary gearbox with a varying crack using a rigid-flexible coupled model, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[39] Y. Zhang, X. Wu and B. Zhang, High structural coverage ABAC policy combination testing method based on a decision inheritance tree and data flow, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[40] D. J. Singh, P. Agrawal, N. K. Verma, A. K. Ghosh and A. Malagaudanavar, Interval type-2 TS fuzzy model for angle of attack sensor of the aircraft, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.

[41] X. Tang, Z. Peng, H. Ding, M. Cheng and S. Yang, Novel distance and similarity measures for hesitant fuzzy sets and their applications to multiple attribute decision making, *Journal of Intelligent & Fuzzy Systems (JIFS)* **XX** (2018), XX-XX.