Artificial Intelligence in Industrial Systems

ARTIFICIAL intelligence has played an important role in industrial community over the last decades. Benefited from the recent progress in data acquisition and high-performance computing, artificial intelligence technology has gained a great development, and plenty of industrial products have been built with intelligent abilities. Artificial intelligence techniques improve the performance of industrial systems, whereas the practical applications in industry inspire the theoretical advances of artificial intelligence in turn. Although artificial intelligence has shown great success in solving real-world problems, there is still room for improvement due to the complexity of industrial tasks.

This Special Section aims to propose the most recent work on the application of artificial intelligence in industrial systems, and presents new theories and algorithms toward addressing the remaining issues. The 29 papers that constitute this Special Section (a total of 89 papers were received) put forward a variety of algorithmic techniques covering a wide range of topics, such as detection, tracking, recognition and classification for industrial perception, action and activity analysis for industrial systems, intelligent human–machine interaction techniques, data analysis in industrial product design, multisource date fusion for industrial systems, and performance evaluation and benchmark datasets for industrial systems.

Concerning the subject detection, tracking, recognition, and classification for industrial perception, [item 1) in the Appendix] designs a deep learning based visual inspection system for welding defection detection. The proposed system utilizes the data augmentation and transfer learning methods to train a deep neural network with about seven million parameters. During the operation, the system is able to collect data and extend the dataset. With the increasing of the dataset size, the training procedure is repeated to improve the performance. The results show that deep neural networks can be successfully applied in the quality inspection tasks, which were usually performed by human operators. The paper [item 2) in the Appendix] puts forward a unified framework to detect and count vehicles from drone images. Based on the expected squared error, an effective loss is designed to push the anchors toward matching ground truth boxes with adaptive scale, and the bottom–up and top–down attention mechanism is used to extract features. Then, the counting layer with regularized constraint is combined into the loss function of object detection to improve the accuracy of both vehicle detection and counting. Experiments on several real-world datasets show the superiority of the proposed framework over the state of the arts. In [item 3) in the Appendix], a multichannel network to detect and distinguish human's right/left hands from images was developed. The first channel of the network extracts hand feature for hand detection, whereas the second channel models the human body pose and estimates the position of the hands. Afterward, the estimated hand position is used to correct the result of hand detection, and distinguish the right and left hands. In this way, the output of the two channels are fused. Results demonstrate that the proposed network is able to perform hand detection and recognition in real time. The paper [item 4) in the Appendix] presents a robot localization system. An unmanned aerial vehicle (UAV) is used to obtain a shared environment map from the global view and transfers the map to all the ground robot. Therefore, the ground robot can determine its localization with respective to the UAV by employing the geometric information. Then, the map is simplified into a two-and-a-half-dimensional city map, and the global pose of the ground robot is estimated. To deal with the drastically different views of air–ground robots, an automatic collaborative localization strategy is also designed. Experiments in an industrial environment validate the outstanding localization results of the proposed system. The paper [item 5) in the Appendix] tackles the anomaly detection problem in industrial cases. A vertex-weighted hypergraph is constructed for the training data, where each vertex corresponds to a sample. The correlation among the samples is also captured in the graph. To deal with the unbalanced data, each vertex is assigned with a weight according to its similarity score and isolation score. Finally, graph learning technique is employed to learn the label of each vertex, and the anomaly detection goal is accomplished. The proposed method is able to investigate the effect of each sample on the detection task.

For the topic action and activity analysis for industrial systems, [item 6) in the Appendix] designs an activity recognition framework based on the neural network. By utilizing the MobileNet convolution neural network (CNN) model, the surveillance video stream is first partitioned into important shots, which contain the activities. Then, the FlowNet2 is used to extract the temporal optical flow features. Finally, the obtained features are fed into the multilayer long short-term memory (LSTM), which is able to model the long-term sequences. Experiments on activity recognition demonstrate the effectiveness of the proposed framework in industrial scenarios. The paper [item 7) in the Appendix] presents a lightweight learning-based framework to understand the manual assembly. The MobileNet CNN model is incorporated into the single shot multibox detector networks to detect the hands in videos. Then, a tracking strategy is proposed to associate the hand bounding boxes in consecutive frames. After obtaining the trajectories of hands, a temporal action recognition model is used to analyze the content of hand operations. The proposed framework can understand the actual state of the assembly process, which helps to improve the quality control and production planning.

Digital Object Identifier 10.1109/TIE.2019.2916709

Intelligent human–machine interaction techniques have been tackled in the paper [item 8) in the Appendix] that introduces an end-to-end cost sensitive parallel neural network to learn the operation of insurance data. The proposed framework processes the heterogeneous insurance data into a parallel architecture and learns a cost-sensitive matrix to handle the imbalanced data. During the training stage, both the network parameter and the cost-sensitive matrix are optimized. Then, a real-world insurance intelligence operation system is established, which deals with the insurance operation problems with end-to-end process. The paper [item 9) in the Appendix] presents a gradient descent least squares regression based network for controlling grid-integrated solar photovoltaic system. The proposed algorithm attenuates harmonic components, noise, dc offsets, bias, notches, and distortions from nonlinear signals, so that the power quality can be improved under both normal and abnormal conditions. The established system performs well on a developed prototype, and the results satisfy the IEEE-519 standard. The paper [item 10) in the Appendix] proposes an energy optimization-based system for the assisting users to push power-assisted wheelchairs with a suitable fatigue level. The assistive task is considered as an optimal control problem, which is further solved by the online model-free reinforcement learning methods. In this way, the electrical energy is minimized while the desired fatigue level is maintained. Simulation results show that the proposed system can adapt to the human fatigue dynamics changes. The paper [item 11) in the Appendix] presents an intelligent electricity demand forecasting system for fused magnesium smelting process. In the proposed system, a mechanism model is combined with a data-driven model. To identify the order of the data-driven model, the maximal information coefficient method is combined with the rule reasoning. Meanwhile, an intelligent saturated alternating identification algorithm is put forward to avoid the mutual effect between the mechanism model and the data-driven model. Industrial applications validate the effectiveness of the proposed system. Still in the context of intelligent human–machine interaction techniques, [item 12) in the Appendix] develops a two-stage optimal design system to control the total power loss in the hybrid ac–dc microgrid applications. In the first stage, the total power loss of CLLC resonant converter is optimized. In the second stage, the optimal leakage inductances and magnetizing inductance are obtained. The proposed system demonstrates that artificial intelligence is applicable for total power loss optimization. The effectiveness of the system is demonstrated by an example of a real converter. Still in the context of intelligent human–machine interaction techniques, [item 13) in the Appendix] designs a personalized travel recommendation system. Based on domain adaptation, a unified classifier is first developed to detect landmark styles. Then, both the detected landmark styles and the user's travel history are jointly utilized to learn the style-oriented preferences. Finally, the style-oriented landmark recommendation system is established, which takes both the user's style and the characteristics of the must-go landmarks into consideration. Experimental results prove that it is important to include both the long-term and short-term style preferences in recommendation, and the local contexts, such as landmark location and popularity, should be also considered.

The subject of data analysis in industrial product design has been considered, [item 14) in the Appendix] proposes a hybrid feature transformation and compression method to diagnose the high-voltage circuit breaker fault. Basic characteristic description is first generated with the traditional wavelet transformation time–frequency analysis. Meanwhile, a random forest is used to extend the feature width. Then, a stacked autoencoder is employed to compress the feature depth. Finally, five classifiers are utilized to accomplish the fault diagnose task. Comparative experiments verify the superiority of the proposed framework. The paper [item 15) in the Appendix] introduces a hierarchical backtracking-based parameter learning method for surface mount chips with small outline transistor packages. The Gaussian mixture model and random walk watershed algorithms are jointly combined to extract the lead regions of the chips. Then, the lead regions are grouped by a hierarchical backtracking algorithm to obtain chip models. Finally, the root set pyramids are employed to eliminate the redundant models. Experimental results show that the proposed method is effective in parameter learning and robust to noise. The paper [item 16) in the Appendix] introduces a supervised subspace learning method. The neighbor relationship of the data samples is utilized to exploit the geometric structure, where marginal samples are captured. Based on the marginal samples, discriminant analysis is performed, and the low-dimensional representation is extracted. Since the proposed method depends on the multiple marginal pairs, it can handle the data with complex structures. Besides, by utilizing the between-class matrix, the proposed method has the capability to learn the intrinsic feature dimension automatically. The paper [item 17) in the Appendix] presents a new electromagnetic compatibility management method for cell phones. First, the electromagnetic interference analysis of electronic devices is conducted according to electromagnetic compatibility (EMC) guidelines, engineers' experience, and design document to determine the primary interference and sensitive units. Then, a knowledge graph constructed, where the units are stored as entities and new triple functions are defined to associate these entities. Finally, the parameters of the trip functions are learned with the interactive sessions and the EMC management report is obtained according to the results of the triple function. Experiments verify the feasibility and usefulness of the proposed framework. The paper [item 18) in the Appendix] proposes a new method to identify the fault location and fault-type of sensors in the power drive system. The extreme learning machine is adopted to train the sensor faulty dataset and ensemble classifiers are developed to increase the diagnosis accuracy. To balance the tradeoff between the diagnosis accuracy and speed, a time-adaptive fault diagnosis process is designed. The proposed method can identify the stuck fault, offset fault, noise fault of phase current, dc-link voltage, and speed sensor with high diagnosis accuracy. The paper [item 19) in the Appendix] designs a fast image up-sampling method for industrial applications at low magnification. First, the edge and nonedged areas are distinguished and reconstructed by different approaches. For edge areas, the local edge patterns are encoded by an efficient local encoding process and each pattern is reconstructed with a learned projection matrix. For nonedged areas, a back-projection method is introduced to refine the textural details. Finally, the results are refined by an additional postprocessing. Experiments show that the proposed method achieves comparable results with very low computational cost. The paper [item 20) in the Appendix] proposes a new blind deblurring approach in which a L_0 penalty function of both gradient and image is formulated into the total energy function. By adding constraints to the dark channel of sharp image, the proposed method avoids over smooth in the final restoration. The proposed problem is decomposed into two subproblems that are solved in the frequency domain to improve the efficiency of computing. The half-quadratic splitting method is also employed to ensure the convergence of the proposed algorithm. Experiments show that the proposed method significantly enhance the edges of objects in image restoration application. The paper [item 21) in the Appendix] introduces an intelligent system for driver-automation shared driving control. The proposed system consists of the driving decision making part and the vehicle trajectory adaptation part. The drivers are allowed to choose a desired position within the road lane rather than imposing the lane centerline, such that the driver-automation conflict is reduced and the driver is provided with more freedom. Both objective and subjective evaluations demonstrate the effectiveness of the proposed planning algorithm. The paper [item 22) in the Appendix] presents a deep coupled dense convolutional network with complementary sensor data to integrate information fusion, feature extraction, and fault classification together for intelligent diagnosis. In the proposed approach, the built-in encoder signal and external vibration signal are used as the analysis objects in parallel to obtain more abundant condition information. When compared with traditional diagnosis methods that depend on the handcrafted features and the shallow classification model, the proposed method may be a more powerful approach for intelligent diagnosis. The experiments on a planetary gearbox experiment rig illustrate the effectiveness of the proposed method.

Concerning multisource data fusion for industrial systems, [item 23) in the Appendix] presents a semisupervised hashing method for large-scale crows-media search, which integrates both the deep feature learning and the semantic binary code learning in a unified framework. The unified binary code of multisource data is generated without relaxation by solving the discrete constrained objective function in an alternating manner. Furthermore, the neighborhood structure of the input data is captured during the code learning procedure, and the optimization is speeded up by a binary gradient descent algorithm. The paper [item 24) in the Appendix] proposes an active fusion approach for multimodal material recognition. To minimize the gap among multimodal data, the adversarial dictionary learning method is adopted to learn the modal-invariant representation. Meanwhile, a reinforcement learning method is designed to select the active modality automatically. Experimental results on a publicly available dataset demonstrate the good performance of the proposed framework on material recognition. The paper [item 25) in the Appendix] puts forward an object tracking approach, which combines the information from both red green blue (RGB) and infrared modalities. In order to learn the multimodal feature template for appearance modeling, a modality consistency feature template learning algorithm is developed. The learning algorithm achieves the modality consistency in both the representation and discriminability levels. An effective optimization algorithm is also derived to learn the feature template learning model. The paper [item 26) in the Appendix] proposes a multistep modeling and optimizing algorithm to learn the multiple energy system that contains various energy systems, such as electricity and natural gas. The proposed method divides a complex energy hub model into several simple models and solves the original nonlinear problem by substituting the variables in each simple model. The proposed method is applicable for the large-scale multiple energy systems and can obtain optimal operation decision steadily.

For performance evaluation and benchmark datasets for industrial systems, [item 27) in the Appendix] detects the concealed object, such as knife and phone, in the active millimeter wave images. To facilitate the computational speed, the lightweight network is taken as the backbone network. Then, the dilated convolution is employed to enlarge the resolution of feature maps, and a context embedding module is also incorporated. Therefore, the proposed detector is able to capture both the details and context information. Meanwhile, a large-scale dataset is also constructed for performance evaluation, which contains more than 50 000 images. The paper [item 28) in the Appendix] presents a data-driven framework to forecast the solar irradiation. Boosted regression trees, artificial neural networks, support vector machine and least absolute shrinkage, and selection operator are applied to model the spatial relationship between the solar irradiation at the targeted site and its neighboring sites. Meanwhile, the solar irradiation at a targeted site is also forecasted. Comprehensive experiments show that the boosted regression tree model achieves the best performance, and demonstrate that the proposed framework is applicable for the short-term forecasting of ground-based global horizontal irradiation at the targeted site. The paper [item 29) in the Appendix] presents a method to measure the refrigeration capacity of hermetic compressors in extremely short times. To deal with the nonlinear correlation among the variables, artificial intelligence networks are utilized. Moreover, the proposed algorithm measures the rate of pressure rise imposed by the compressor instead of measuring the refrigeration capacity directly, so the measurement time is significantly shortened. Experiments show that the proposed method can measure the refrigeration capacity of a compressor in less than 7 s.

We hope that the reader appreciates the content of this Special Section.

R. M. Palhares, *Guest Editor*
Federal University of Minas Gerais
Belo Horizonte 31270-901, Brazil

Y. Yuan, *Guest Editor*
Northwestern Polytechnical University
Xi’an 710072, China

Q. Wang, *Guest Editor*
Northwestern Polytechnical University
Xi’an 710072, China

Acknowledgment

The Guest Editors would like to thank Prof. L. Franquelo, the past Editor-in-Chief, for his recommendations and support. The Guest Editors would also like to thank Prof. E. Levi, the current Editor-in-Chief, for the guidance in this editorial. Special thanks goes to all authors who have contributed with their findings to enrich this Special Section. Last but not least the Guest Editors thank all reviewers who patiently spent their time for improving the content of this editorial.

Appendix
Related Work

1) P. Sassi, P. Tripicchio, and C. A. Avizzano, "A smart monitoring system for automatic welding defect detection," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9641–9650, Dec. 2019.
2) W. Li, H. Li, Q. Wu, X. Chen, and K. N. Ngan, "Simultaneously detecting and counting dense vehicles from drone images," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9651–9662, Dec. 2019.
3) Q. Gao, J. Liu, Z. Ju, and X. Zhang, "Dual-hand detection for human-robot interaction by a parallel network based on hand detection and body pose estimation," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9663–9672, Dec. 2019.
4) J. Zhang, R. Liu, K. Yin, Z. Wang, M. Gui, and S. Chen, "Intelligent collaborative localization among air-ground robots for industrial environment perception," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9673–9681, Dec. 2019.
5) N. Wang, Z. Zhang, X. Zhao, Q. Miao, R. Ji, and Y. Gao, "Exploring high-order correlations for industry anomaly detection," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9682–9691, Dec. 2019.
6) A. Ullah, K. Muhammad, J. Del Ser, S. W. Baik, and V. H. C. de Albuquerque, "Activity recognition using temporal optical flow convolutional features and multilayer LSTM," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9692–9702, Dec. 2019.
7) L. Liu, Y. Liu, and J. Zhang, "Learning-based hand motion capture and understanding in assembly process," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9703–9712, Dec. 2019.
8) X. Jiang, S. Pan, G. Long, F. Xiong, J. Jiang, and C. Zhang, "Cost-sensitive parallel learning framework for insurance intelligence operation," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9713–9723, Dec. 2019.
9) N. Kumar, B. Singh, and B. K. Panigrahi, "Framework of gradient descent least squares regression-based NN structure for power quality improvement in PV integrated low-voltage weak grid system," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9724–9733, Dec. 2019.
10) G. Feng, L. Busoniu, T.-M. Guerra, and S. Mohammad, "Data-efficient reinforcement learning for energy optimization of power-assisted wheelchairs," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9734–9744, Dec. 2019.
11) J. Yang, T. Chai, C. Luo, and W. Yu, "Intelligent demand forecasting of smelting process using data-driven and mechanism model," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9745–9755, Dec. 2019.
12) B. Zhao, X. Zhang, and J. Huang, "AI algorithm-based two-stage optimal design methodology of high-efficiency CLLC resonant converters for the hybrid ac–dc microgrid applications," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9756–9767, Dec. 2019.
13) J. Shen, Z. Cheng, M. Yang, B. Han, and S. Li, "Style-oriented personalized landmark recommendation," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9768–9776, Dec. 2019.
14) S. Ma, M. Chen, J. Wu, Y. Wang, B. Jia, and Y. Jiang, "High-voltage circuit breaker fault diagnosis using a hybrid feature transformation approach based on random forest and stacked auto-encoder," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9777–9788, Dec. 2019.
15) H. Sun, J. Yu, W. Liu, and X. Yang, "hbtSOTLearner: A hierarchical backtracking based parameter learner for small outline transistor," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9789–9797, Dec. 2019.
16) Z. Huang, H. Zhu, J. T. Zhou, and X. Peng, "Multiple marginal Fisher analysis," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9798–9807, Dec. 2019.
17) D. Shi, F. Zhang, N. Wang, and W. Fang, "Intelligent electromagnetic compatibility management of cell phones by using knowledge graphs," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9808–9816, Dec. 2019.
18) B. Gou, Y. Xu, Y. Xia, G. Wilson, and S. Liu, "An intelligent time-adaptive data-driven method for sensor fault diagnosis in induction motor drive system," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9817–9827, Dec. 2019.
19) W. Jia, Y. Zhao, R. Wang, S. Li, H. Min, and X. Liu, "Are recent SISR techniques suitable for industrial applications at low magnification?," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9828–9836, Dec. 2019.
20) S. Liu, Y. Feng, S. Zhang, H. Song, and S. Chen, "L_0 sparse regularization-based image blind deblurring approach for solid waste image restoration," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9837–9845, Dec. 2019.
21) A. Benloucif, A.-T. Nguyen, C. Sentouh, and J.-C. Popieul, "Cooperative trajectory planning for haptic shared control between driver and automation in highway driving," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9846–9857, Dec. 2019.
22) J. Jiao, M. Zhao, J. Lin, and C. Ding, "Deep coupled dense convolutional network with complementary data for intelligent fault diagnosis," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9858–9867, Dec. 2019.
23) G. Wu, J. Han, Z. Lin, G. Ding, B. Zhang, and Q. Ni, "Joint image-text hashing for fast large-scale cross-media retrieval using self-supervised deep learning," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9868–9877, Dec. 2019.

24) H. Liu, F. Sun, and X. Zhang, "Robotic material perception using active multimodal fusion," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9878–9886, Dec. 2019.
25) X. Lan, M. Ye, R. Shao, B. Zhong, P. C. Yuen, and H. Zhou, "Learning modality-consistency feature templates: A robust RGB-infrared tracking system," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9887–9897, Dec. 2019.
26) T. Liu, D. Zhang, H. Dai, and T. Wu, "Intelligent modeling and optimization for smart energy hub," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9898–9908, Dec. 2019.
27) T. Liu, Y. Zhao, Y. Wei, Y. Zhao, and S. Wei, "Concealed object detection for activate millimeter wave image," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9909–9917, Dec. 2019.
28) C. Huang, L. Wang, and L. L. Lai, "Data-driven short-term solar irradiance forecasting based on information of neighboring sites," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9918–9927, Dec. 2019.
29) R. Coral, C. A. Flesch, and R. C. C. Flesch, "Measurement of refrigeration capacity of compressors with metrological reliability using artificial neural networks," *IEEE Trans. Ind. Electron.*, vol. 66, no. 12, pp. 9928–9936, Dec. 2019.

Reinaldo Martinez Palhares (M'14) received the Ph.D. degree in electrical engineering from the University of Campinas, Campinas, Brazil, in 1998.

He is currently a Full Professor with the Department of Electronics Engineering, Federal University of Minas Gerais, Belo Horizonte, Brazil. His main research interests include robust control; fault detection, diagnosis, and prognosis; and soft computing.

Prof. Palhares has been serving as an Associate Editor for the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS and as Guest Editor for the *Journal of The Franklin Institute*—Special Section on "Recent Advances on Control and Diagnosis via Process Measurements;" and for the IEEE/ASME TRANSACTIONS ON MECHATRONICS—Focused Section on "Health Monitoring, Management and Control of Complex Mechatronic System."

Yuan Yuan (M'05–SM'11) received the B.E. degree from the University of Science and Technology of China, Hefei, China, in 2002, and the Ph.D. degree from the University of Bath, Bath, U.K., in 2005, both in signal processing.

She is currently a Full Professor of Computer Science and Technology with the School of Computer Science and the Center for Optical Imagery Analysis and Learning, Northwestern Polytechnical University, Xi'an, China. She has authored or coauthored more than 150 papers including about 100 in reputable journals, such as the IEEE transactions and Pattern Recognition, and also conference papers in the Computer Vision and Pattern Recognition, British Machine Vision Conference, IEEE International Conference on Image Processing, and International Conference on Acoustics, Speech and Signal Processing (ICASSP). Her current research interests include visual information processing and image/video content analysis.

Qi Wang (M'15–SM'15) received the B.E. degree in automation and the Ph.D. degree in pattern recognition and intelligent systems from the University of Science and Technology of China, Hefei, China, in 2005 and 2010, respectively.

He is currently a Professor of Computer Science and Technology with the School of Computer Science and the Center for Optical Imagery Analysis and Learning, Northwestern Polytechnical University, Xi'an, China. His research interests include computer vision and pattern recognition.