Guest Editorial Special Section on AI-Driven Developments in 5G-Envisioned Industrial Automation: Big Data Perspective

WITH the recent advances in information and communication technologies, industrial automation is expanding at a rapid pace. This transition is characterized by "Industry 4.0," the fourth revolution in the field of manufacturing. Industry 4.0, also called as "Industrial Internet of Things (IIoT)" or "smart factories," is a reflection of new industrial revolution that is not only interconnected, but also communicate, analyze, and use the information to create a more holistic and better connected ecosystem for the industries [1]. Additionally, the automation induced by the coupling of Internet of Things (IoT) with industries makes machines intelligent while rendering their capabilities to autonomously exchange information, trigger actions, and operate remotely. However, in order to deliver a rich portfolio of services to the industrial sector, reliability and stability are needed for critical machine-to-machine communication, with short and stable latency times. As a result, industrial automation largely depends upon advanced mobile wireless connectivity to provide a more comprehensive, interlinked, and efficient approach to manufacturing [2]. However, current cellular networks seem to fail in addressing the key requirements of industrial automation, such as augmented reality needs, process automation, and monitoring and controlling a large density of IIoT devices.

Thus, the advent of fifth generation (5G) of mobile communications is expected to act as a global cornerstone for the demanding and diverse requirements of the "factory of the future—Industry 4.0." In order to deliver secure, dependable, and seamless services to the automation pyramid, such as higher data rates, massive connectivity, ultralow latency, high reliability, high mobility support, high-accuracy positioning, and most important availability, 5G supports three essential types of communication, i.e., ultrareliable low-latency communications, massive machine-type communication, and enhanced mobile broadband [3]. As a result, ultralow latency in combination with massive machine communications and intelligent analytics will enable the growth and transformation in smart factories while directly contributing to social and economic development. However, the involvement of a large number of sensors, mobile robots, and autonomous machines is expediting the data that is captured and stored on dependable communication networks. This pervasive and exponentially increasing wireless data traffic is mainly characterized as "big data" [4].

This information-intensive transformation is expected to leverage new possibilities in industries in order to revamp their operations and provide improved scalability, productivity, efficiency, and connectivity. However, achievement of these goals definitely require newer architecture designs and upgraded technologies that can make real-time decisions in an efficient manner. In order to cope with the increasing demands of next generation industrial automation and deliver some actionable insights, artificial intelligence (AI) will likely perform a key enabling role in creating immense opportunities across industrial sectors [5]. Integration of AI with IIoT would lead to the emergence of "connected intelligence" rather than mere "connected devices." This amalgamation is expected to revolutionize smart business solutions including smart dust, smart drones, futuristic farming, smart aerospace, and smart energy networks.

This special section of the IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS is intended to explore the recent findings and research developments on consolidating AI for industrial informatics with a focus on 5G and big data. Particular emphasis is placed on novel techniques, concepts, state-of-the-art solutions, algorithms, modeling, implementation experiments, and applications, which are not just the evolution of Industry 4.0, but also act as key drivers for the next generations of industrial automation. It is interesting to note that the call for papers received an especially strong response from the community, with 14 high-quality papers being eventually accepted, further attesting the rapid development of this scientific area. We hope these articles will show their value over time while being immediately helpful for our current readership. A summary of the accepted papers is provided as follows.

The paper "Fuzzy correlation measurement algorithms for big data and application to exchange rates and stock prices" by Ruan *et al.* introduces three new algorithms, i.e., the centroid-based measure, the integral-based measure, and the α-cut-based measure for measuring the correlation between big data using fuzzy techniques. The proposed methods use fuzzy numbers to represent the continuous exchange rates and stock prices, develop fuzzy correlation measurement algorithms to calculate their correlation coefficients, and further examine the causality direction between these two variables. The authors collected the

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data of Shanghai stock price index to examine the relationship between exchange rates and stock prices. Presented results prove the effectiveness of the work.

In the paper "Big data analysis based network behavior insight of cellular networks for industry 4.0 applications," Jiang *et al.* propose a big data based analysis framework to analyze and extract network behavior patterns in cellular networks for Industry 4.0. The data prehandling and traffic flow extraction approaches are presented to construct the effective traffic matrices. The authors also design the call pattern analysis and network behavior extraction approaches to perform big data analysis and feature extractions. Then, the corresponding algorithms are proposed to characterize the network behaviors based on cellular call patterns and network resource usage. The detailed evaluation on real-time mobile call datasets validate the effectiveness of the proposed method.

In the paper "Big data cleaning based on mobile edge computing in industrial sensor-cloud," Wang *et al.* present a new method of data cleaning for wireless sensor networks, which aims to accelerate the cleaning speed of abnormal data and reduce the upload bandwidth and energy consumption in sensor cloud system while maintaining data reliability and integrity. Specifically, the authors consider an angle-based outlier detection method to obtain the training data and combine machine learning with the edge computing platform to optimize the cleaning model in real time. Theoretical analysis and experiments validate that the proposed mechanism outperforms traditional data cleaning algorithms in terms of delay, energy consumption, and the network lifetime.

The paper "Gender profiling from a single snapshot of apps installed on a smartphone: An empirical study" by Zhao *et al.* discusses an interesting problem for integration of 5G networks and AI to create a more holistic and better connected ecosystem for the industries. Especially, the authors tackle the gender profiling problem based on snapshot of apps installed on their smartphones. The gender differences are discovered from installed App lists, and the predictive ability for gender is investigated. In particular, the authors apply information gain mechanism to select the most discriminative apps while latent Dirichlet allocation method is adopted to learn the semantic topics from the app description. The authors also provide a comprehensive analysis based on a real-world large-scale dataset. As a further insight, the authors discuss the implications and limitations of the study in detail.

The paper "Deep-learning-based small surface defect detection via an exaggerated local variation-based generative adversarial network" by Lian *et al.* employ machine vision and deep learning theory, and present a defect exaggeration approach by joining a generative adversarial network and convolutional neural network. The rationale behind this work is to handle the local variations on various surface images, included in the shape, color, and combination of geometry and color. Specifically, it leverage an adversarial network to generate numerous defect exaggerated samples, which are used to enhance the accuracy of classifiers. The proposed method is evaluated using different types of surface image samples, where defect detection accuracy is used to measure the performance in comparison with the state-of-the-art approaches.

In the paper "When deep reinforcement learning meets 5G-enabled vehicular networks: A distributed offloading framework for traffic big data," Ning *et al.* construct an intelligent offloading schedule framework for 5G vehicular networks, which jointly utilizes licensed cellular spectrum and unlicensed channels. The authors first formulate an optimization problem to minimize the offloading cost. Due to its complexity, it is divided into two subproblems in a heuristic manner, i.e., a two-sided matching algorithm for unlicensed spectrum scheduling and a deep reinforcement learning-based method for cellular channel allocation. Performance analysis based on real-world traces of taxies illustrate the effectiveness of the presented solution.

The paper "NELLY: Flow detection using incremental learning at the server side of SDN-based data centers" by Estrada-Solano *et al.* introduces a novel approach called NELLY that deals with the problem of identifying elephant flows at the server side of software-defined datacenter networks. The authors hypothesize that the proposed scheme exploits incremental learning so as to adjust itself to dynamic traffic conditions while also avoiding memory waste. The proposal is supported via numerical results that are carried out under real-time network traffic data on which different incremental learning algorithms were introduced. Adaptive decision trees have been shown to be the most feasible choice to achieve high accuracy and high classification speed.

In the paper "ConnSpoiler: Disrupting C&C communication of IoT-based botnet through fast detection of anomalous domain queries," Yin *et al.* propose a lightweight system that detects IoT-based botnets by training a threshold random walk model with popular domain names. It works by classifying the streams of random nonexistent domain names queries in a fast way to create chances for disrupting the command and control connection. The proposed approach is evaluated using real-world DNS traffic collected from two different large ISP networks, where results demonstrate accurate identification of devices with unknown botnets.

The paper "Smart collaborative automation for receive buffer control in multipath industrial networks" by Song *et al.* presents a smart collaborative automation scheme, which is designed to improve the utilizations and overcome the buffer limitations. A mathematical model is established to describe the main system operations with considerations of chunk loss. The disordered chunk expectation is calculated and used in locating the critical condition of round number. Then, a comprehensive policy selection algorithm considering in-time situations is presented, which demonstrates good performance in term of transmission capacity and buffer utilization.

The paper "Intelligent quality of service aware traffic forwarding for software-defined networking/open shortest path first hybrid Industrial Internet" by Bi *et al.* studies an intelligent traffic forwarding issue in software-defined networking (SDN)/open shortest path first hybrid industrial Internet. Particularly, the authors propose a Quality of Service (QoS) aware forwarding strategy for the industrial applications by adopting single-path

minimum cost algorithm and *K*-path partitioning technique. Simulation results demonstrate that the proposed scheme can guarantee the QoS requirements including packet loss rate, link utilization, and link delay into consideration, which are critically important to QoS-aware industrial applications.

In the paper "Dynamic embedding and quality of service-driven adjustment for cloud networks," Cao *et al.* investigate the dynamic resource allocation problem and readjustment in cloud networks. The authors consider a novel dynamic QoS metric triggered adjustment instead of static one-time resource mapping, leading to the improvement of physical resource utilization and cloud network performance. Further, a dynamic and QoS-driven mapping algorithm is utilized to ensure virtual network (VN) assignments and fulfill the QoS demands. Authors report experimental validation based on VN acceptance ratio, CPU utilization, node memory utilization, node storage utilization, communication bandwidth utilization, and average virtual element delay.

The paper "Automobile driver fingerprinting: A new machine learning based authentication scheme" by Xun *et al.* focuses on security issues in automobiles. The authors design a real-time automobile driver fingerprinting scheme to ensure the safety of people's properties and even lives. Different from previous work concerning automobile driver fingerprinting, they conduct a comprehensive study on behavioral characteristics of drivers. Then they construct a combined model based on convolutional neural network and support vector domain description to achieve an efficient automobile driver fingerprinting. Extensive experimental results show that the proposed driver fingerprinting scheme can dynamically match the driver's identity in real-time without affecting the normal driving.

In the paper "Online GMM clustering and mini-batch gradient descent based optimization for Industrial IoT 4.0," Messaoud *et al.* propose a resource allocation scheme for IIoT, which combines the strength of SDN and network function virtualization technologies. Different from the existing models, the proposed approach employs an adaptive and online machine learning algorithm along with an intraslicing algorithm; wherein each slice of the network is dedicated to a category of services having similar QoS requirement level. The proposed scheme operates in three phases: IoT devices assignment to the slices based on online network function virtualization algorithm; interslice resource reservations based on minibatch gradient descent; and slice resource allocations based on the max-utility algorithm. The proposed solution is evaluated using a set of IoT devices, where packer error rate, energy consumption, and reducing delay are used to demonstrate the efficiency of the proposed slicing model in comparison to the traditional approaches.

In the paper "A shared bus profiling scheme for smart cities based on heterogeneous mobile crowdsourced data," Kong *et al.* present a heterogeneous crowdsourced data based shared bus profiling scheme in order to overcome the data scarcity issue. Then, the authors present a travel profiling by merging shared bus data generation and collection, travel requirement description method, and route optimization algorithm, to profile shared buses and offer constructive suggestions for its development. The proposed approach is evaluated using the real-world shared bus datasets, with results demonstrating the accurate characterization of the passengers' travel requirements in terms of describing passenger flow, travel time, waiting time, and loss tolerance.

We would like to express our sincere gratitude to all the authors who submitted their valuable findings as well as to the highly qualified reviewers who voluntarily participated in the review process and provided constructive feedback on a very tight schedule. The Guest Editors are immensely grateful to the Editor-in-Chief, Prof. R. C. Luo, for the timely opportunity to initiate this Special Section and for his support and guidance in preparing and finalizing this special section. Special thanks goes to the Administrators of the journal, for their excellent and continuous support leading to publication. We sincerely hope that this Special Section will stimulate and encourage researchers to continue working on this exciting and influential area.

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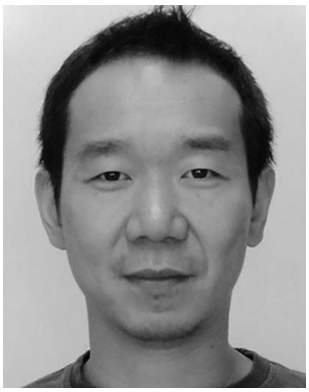

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