Guest Editorial: Emerging Technologies and Novel Trends in Industrial Informatics

INDUSTRIAL informatics is a very dynamic and open-ended research area investigating the application of computing in different industrial domains. The international conference on Industrial Informatics (INDIN) was established by the IEEE Industrial Electronic Society in 2003 in order to bridge the significant gap between the high expectations of practice and the state-of-the-art in industry and academic research [item 1) in the Appendix]. Its intention is to provide a dynamic platform for researchers in industry and academy to present their cutting-edge results, and by doing that, form the global industrial informatics agenda. About the same time, the IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS were established with the first issue published in early 2005. Since then, both the conference and the transactions went hand in hand with many cases of publishing extended versions of conference papers in the transactions.

This special section is the result of an experiment, Fast Track to the Transactions at the 17th edition of INDIN held in Finland at Aalto University on July 22–25, 2019. The fast track idea, introduced originally at the Workshop of Factory Communication Systems (WFCS) [item 19) in the Appendix], [item 20) in the Appendix], is to accelerate the publication of the best conference results in the transactions. Authors who wanted to be considered for the fast track had to submit their artiles in the format of an eight pages long Transactions paper. Thus, the conference review process was the first step in the Transactions review. This model proved to be highly popular, with 100 papers submitted for the consideration, of which 45 were recommended for the transactions' submission. This special section "Emerging Technologies and Novel Trends in Industrial Informatics" has been created at the Transactions for submission of full papers. The articles went through a very thorough review process of the Transactions, the result of which are the 12 papers included in this Special Section (three more papers were accepted but will be published in the general issue of the transactions).

The wide spectrum of the current Industrial Informatics areas is represented by 14 technical tracks and 14 special sessions. While the technical tracks represent established domains, special sessions allow for more emerging topics. In 2019, the conference had the motto "Industrial Applications of Artificial Intelligence" following the globally skyrocketing interest to Artificial Intelligence (AI). AI has been an enabler and facilitator of Industrial Informatics with varying degrees of interest and success over time. In the current context, the ability to leverage AI for real-time monitoring and real-time control is predicted (and in some instances actualised) to be the primary driver of tactical leverage, strategic advantage, competitive strength, leading toward fully autonomous, intelligent systems that achieve organizational objectives, as well as social, economical, and environmental obligations [item 2) in the Appendix].

The track on Artificial Intelligence at INDIN'19 was the biggest in the conference with 35 accepted papers. What is remarkable is that AI-related papers were present also in many other tracks. A half of this Special Section, i.e., six papers [items 6–11) in the Appendix], are developing or using different AI techniques for technical applications.

Wireless communications are another hot topic coming rapidly to the industrial application domains, such as autonomous vehicles and factory automation. Wireless interfaces are appealing since they allow us to reduce the cabling and to connect devices that cannot be reached via a wired connection, such as nodes mounted on mobile equipment [item 3) in the Appendix]. On the other hand, it is imperative to guarantee the timing behavior of critical traffic and provide temporal isolation from noncritical communication [item 4) in the Appendix], as well as tight integration with the application layers [item 21) in the Appendix]. Some of the key technologies are 5G, Wi-Fi, and long-range low-power networks, represented in this section by [item 12) in the Appendix], [item 13) in the Appendix]. Wireless communications are more and more combined with advanced computing architectures, such as Cloud, Edge, and Fog, e.g., [item 14) in the Appendix], and Software-Defined Networking [item 18) in the Appendix]. Industrial edge computing is designed to facilitate agile connectivity, real-time control, and data optimization, while enabling intelligent applications, ensuring tight security, and protecting privacy [item 5) in the Appendix]. This is particularly important in the increasingly complex industrial automation systems represented, for instance, by the Industry 4.0 idea [item 22) in the Appendix]. Industry 4.0 and the cutting-edge computing technologies are addressed in this Special Section in [item 16) in the Appendix] and digital twins in the form of virtual sensors development for microfactories on chip are dealt with in [item 17) in the Appendix]. The user view, i.e., human-centric informatics combining technical and social aspects are represented in this Special Section by healthcare application [item 10) in the Appendix] of machine learning and privacy preservation in the Internet of Things [item 15) in the Appendix].

I. PAPERS INCLUDED IN THIS SPECIAL SECTION

The article "Mesoscale Particle Size Predictive Model for Operational Optimal Control of Bauxite Ore Grinding Process"

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[item 6) in the Appendix] by Lu and Chai investigates the use of a mesoscale kinetic model to cooperate with the operational optimal control of bauxite ore grinding process in aluminium production. A novel modeling framework is proposed where a discretized distributed parameter macroscale model and a mesoscale kinetic model are combined to predict the grinding product particle size. The model of the process is described as a stochastic process. The high computational demand has prevented in the past the use of the kinetic model in real time. The authors overcome this problem by embedding an acceleration algorithm based on the τ-leap method. The proposed model is validated using experimental data. Finally, the integration of the predictive model into the bauxite ore grinding operational optimal control framework is demonstrated. At INDIN'19, the paper was presented in the Technical Track on "Distributed and Networked Control and Automation Systems."

The article "Toward New Retail: A Benchmark Dataset for Smart Unmanned Vending Machines" [item 7) in the Appendix] by Zhang *et al.* addresses the lack of appropriate classification datasets for object detection in the unmanned retail applications. The authors have collected more than 30 000 images of unmanned retail containers using a refrigerator affixed with different cameras under both static and dynamic recognition environments. These images were categorized into ten kinds of beverages. After manual labeling, images in the constructed dataset contained over 150 000 instances, each of which was annotated with a bounding box. Extensive experiments on this dataset were performed using ten state-of-the-art deep learning-based models. Experimental results indicate great potential of using these deep learning-based models for real-world smart unmanned vending machines. At INDIN'19, the paper was presented in the Special Session on "Efficient Multimedia Sensing and Computing on Industrial Applications."

The article "Time–Critical Wireless Networked Embedded Systems: feasibility and experimental assessment" [item 8) in the Appendix] by Branz *et al.* investigated an innovative solution to implement high sampling frequency industrial control by means of networked embedded systems connected via Wi-Fi. The basic idea relies on a codesign approach for the control application, which is then able to adapt its sampling period, as well as to tune the Wi-Fi parameters, according to the feedback coming from the network. To this end, the authors implemented a cross-layer architecture that features a robust frame-delay state estimator, a time-efficient communication policy, and a specific tuning of the critical protocol parameters. Hardware-in-the-loop experiments have been carried out with two different off-the-shelf available embedded platforms. The preliminary results, obtained from an extensive experimentation show that the proposed architecture enables industrial control applications requiring a sampling rate up to 1000 Hz, even in the presence of communication impairments. At INDIN'19, the paper was presented in the Special Session on "Communications and Computing for Fog Based Control Systems."

The article "Short-term Forecasting of Heat Demand of Buildings for Efficient and Optimal Energy Management Based on Integrated Machine Learning Models" [item 9) in the Appendix] by Eseye and Lehtonen proposes a novel integrated machine learning technique to forecast the heat demand of buildings. The proposed demand forecasting model is based on the integration of empirical mode decomposition, imperialistic competitive algorithm, and support vector machines. The performance of the proposed forecasting model is tested using a one-year dataset of district heat consumption. Comparative analysis of the forecasting performance of the models was performed and the obtained results demonstrate that the devised model forecasts the heat demand with improved performance. The devised model outperforms other nine evaluated models in terms of the forecasting accuracy. At INDIN'19, the paper was presented in the Technical Track on "Technologies and Infrastructures for Smart Grids, Buildings and Cities."

The article "Hierarchical Two-Stream Growing Self-Organizing Maps with Transience for Human Activity Recognition [item 10) in the Appendix] by Nawaratne *et al.*, addresses the recognition of complex human movements for video surveillance applications. The current techniques in this area use supervised deep learning pipelines, which are unable to learn from nonlabeled video streams. The authors propose a new adaptation of the Growing Self-Organizing Map that adopts two proven concepts of the traditional deep learning, hierarchical, and multistream learning, applied to accommodate learning from nonlabeled video data and their diverse characteristics. The paper demonstrates that the proposed model working using three benchmark video datasets. The results confirm its validity and usability for human activity recognition. At INDIN'19, the paper was presented in the Technical Track on "Artificial Intelligence in Industrial Applications."

The article "Privacy Preservation in Industrial IoT via Fast Adaptive Correlation Matrix Completion" [item 11) in the Appendix] by Lalos *et al.* proposes efficient privacy preservation techniques for industrial IoT applications, which are important in the Industry 4.0. The method uses tracking the correlation of multivariate streams recorded in a network of Industrial IoT devices. The time varying data covariance matrix is used to add noise, which cannot be easily removed by filtering, generating obfuscated measurements, and thus preventing unauthorized access to the original data. The robustness, efficiency, and effectiveness of method were validated using extensive simulations with constrained industrial IoT devices. At INDIN'19, the paper was presented in the Technical Track on "Industrial Informatics Tools."

The article "Virtual Sensor Development for Continuous Microfluidic Processes" [item 12) in the Appendix] by García-Camprubí *et al.* addresses continuous microfluidic processes used for example in factories-on-chip. In such systems the most valuable variables to be sensed for implementing an optimal control are usually not accessible. This paper presents a methodology for building an accurate virtual sensor, based on computer simulations, both analytical and numerical, and model order reduction techniques. The methodology is applied to a given flow-focusing microchip. The main challenge of this approach is to minimize uncertainties associated with the microfluidics setup. The outcome is a virtual sensor that is a real-time model able to predict the shape and location of the multiphase fluid interfaces from the volumetric flow rate measured in the system. Results are successfully validated against experimental data. At INDIN'19, the paper was presented in the Special Session on "Innovative Technologies and Methods for Zero

Defect Manufacturing on Industrial Cyber-Physical Systems Context."

The article "DATA: Dependency-Aware Task Allocation Scheme in Distributed Edge Clouds" [item 13) in the Appendix] by Lee *et al.* proposes the distributed edge cloud concept to overcome the limitation of standalone edge cloud in terms of computing power and resource. Application tasks are distributed to multiple edge clouds for collaborative processing. To maximize the effectiveness of the distributed edge cloud, the paper formulates an optimization problem of task allocation to minimize the application completion time. To mitigate high complexity overhead in the formulated problem, a low-complexity heuristic algorithm called dependence-aware task allocation (DATA) algorithm is developed. Evaluation results demonstrate that DATA can reduce the application completion time up to by 15–32% compared to conventional dependence-unaware task allocation schemes. At INDIN'19, the paper was presented in the Special Session on "5G for Vertical Industry Services."

The article "Automated Decision Support System for Lung Cancer Detection and Classification via Enhanced RFCN with Multilayer Fusion RPN" [item 14) in the Appendix] by Masood *et al.* proposes an enhanced automated decision support system for early lung cancer detection and classification. This research contribution addresses an extremely appealing problem. While the detection of lung cancer at early stages is critical, the conventional method for detecting nodule presence in computed tomography images is tedious as it relies on the radiologists reading the images to prescribe follow-up treatment. The paper proposes a novel image classifier framework. The method allows to automatically select the potential region-of-interest. The system has been trained and evaluated using an open dataset, and the experimental results showed the superior detection performance in comparison to the state-of-the-art nodule detection/classification methods, achieving a sensitivity of 98.1% and classification accuracy of 97.91%. At INDIN'19, the paper was presented in the Special Session on "Informatics Methods for IoT-enabled Health Care."

The article "NB-IoT vs. LoRaWAN: An Experimental Evaluation for Industrial Applications" [item 15) in the Appendix] by *Ballerini et al.* evaluates the two most promising low-power and long-range communication technologies for IoT: LoRaWAN and Narrow Band IoT (NB-IoT). They are compared with accurate in-field measurements using the same application context for a fair comparison in terms of energy efficiency, lifetime, quality of service, and coverage. This paper also provides design guidelines for future industrial applications with stringent requirements of long-range and low-power wireless connectivity. At INDIN'19, the paper was presented in the Special Session on "Intelligent Application of Consumer Wireless Technologies for Industry."

The article "Chatter Detection and Diagnosis in Hot Strip Mill Process with a Frequency-based Chatter Index and Modified Independent Component Analysis" [item 16) in the Appendix] by Jo *et al.* proposes a framework to monitor the chatter phenomenon and to diagnose the cause variables of chatter occurred in hot strip mill process in steelmaking that is high-frequency vibration suddenly arising in the working rolls. For monitoring chatter, the authors develop a chatter index that quantifies chatter to confirm its occurrence. Based on the data classified as normal by the chatter index, a multivariate statistical process monitoring model for detecting chatter is constructed using the modified independent component analysis method. The monitoring results show that this model outperforms other models based on principal component analysis and independent component analysis. At INDIN'19, the paper was presented in the Technical Track on "System and Software Engineering, Runtime Intelligence."

The article "Automatic State Machine Reconstruction from Legacy PLC Using Data Collection and SAT Solver" [item 17) in the Appendix] by Chivilikhin *et al.* demonstrates how sophisticated formal methods from computer science could contribute to solving one important problem in Industry 4.0, namely the migration of software from legacy automation platforms to the cyber–physical systems of the new generation. Such transfer can lead to significant production downtime, resulting in delays and cost overruns. This paper contributes to the systematic seamless transition by proposing a framework based on automatic synthesis methods that learns the behavior of an existing legacy programmable logic controller and generates state machines that can be incorporated into IEC 61499 function blocks. The proposed algorithms are based on Boolean satisfiability (SAT) solvers. The toolchain architecture is exemplified on a laboratory scale mechatronic system. At INDIN'19, the paper was presented in the Technical Track on "Industrial Cyber-Physical Systems and Industrial Agents."

The Guest Editors wish all readers an enjoyable reading of the contributions to this special section.

Acknowledgement

The Guest Editors would like to thank all authors of the submitted papers and the reviewers for their support and constructive comments to this special section. In particular, the Guest Editors would like to apologize to those authors whose excellent papers were not included due to limited space and competitive selection process. They also express big thanks to Prof. K. Man who motivated for organization of the INDIN conference and of the fast track in particular, and who greatly contributed at all steps of the editorial activities.

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Valeriy Vyatkin, *Guest Editor*
Department of Computer Science, Computer, and Space Engineering
Luleå Tekniska Universitet,
97871 Luleå, Sweden
Department of Electrical Engineering and Automation,
Aalto University,
02150 Aalto, Finland
vyatkin@ieee.org

LUCIA LO BELLO, *Guest Editor*
University of Catania,
95125 Catania, Italy

THILO SAUTER, *Guest Editor*
Centre for Integrated Sensor Systems,
Danube University Krems,
2700 Wiener Neustadt, Austria
Austria Institute of Computer Technology,
TU Wien, 1040 Vienna, Austria

APPENDIX
RELATED WORK

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Valeriy Vyatkin (Senior Member, IEEE) received the doctoral degree in applied computer science from Taganrog Radio Engineering Institute, Taganrog, Russia, in 1992, the doctoral degree in electrical engineering from Nagoya Institute of Technology, Nagoya, Japan, in 1999, and the Habilitation degree in engineering from the Ministry of Science and Education of Saxony-Anhalt, Saxony-Anhalt, Germany, in 2002.

He is on a joint appointment as a Chaired Professor with Luleå University of Technology, Luleå, Sweden, and a Full Professor with Aalto University, Helsinki, Finland. He is also the Co-Director of the International Research Laboratory "Computer Technologies," ITMO University, Saint-Petersburg, Russia. Previously, he was a Visiting Scholar with Cambridge University, U.K., and had permanent academic appointments with the universities in New Zealand, Germany, Japan, and Russia. His research interests include dependable distributed automation and industrial informatics, software engineering for industrial automation systems, artificial intelligence, distributed architectures, and multi-agent systems applied in various industry sectors, including smart grid, material handling, building management systems, data centres, and reconfigurable manufacturing.

Dr. Vyatkin has been a delegate to the International Electrotechnical Commission Standardisation Committee on IEC 61499 Standard for more than a decade. He is an Associate Editor for the IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, IEEE OPEN JOURNAL OF INDUSTRIAL ELECTRONICS SOCIETY, and IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN INDUSTRIAL ELECTRONICS. He has been a Co-Editor-in-Chief of the *EAI Transactions on Energy Web*. He was the recipient of the Andrew P. Sage Award for the best IEEE Transactions paper in 2012. He has been the Chair of IEEE IES Technical Committee on Industrial Informatics for two terms 2016–2019.

Lucia Lo Bello received the M.S. degree in electronic engineering and the Ph.D. degree in computer engineering from the University of Catania, Catania, Italy, in 1994 and 1998, respectively.

She is a tenured Associate Professor with the University of Catania. She got the Italian National Scientific Habilitation (ASN) as a Full Professor in 2013 and 2017, respectively. She was a Guest Professor with the University of Malardalen, Sweden, in 2014 and a Visiting Researcher with Seoul National University, South Korea. Her current research interests include automotive communications, with a special focus on Automotive Ethernet, IEEE Audio Video Bridging and Time-Sensitive Networking, industrial networks, real-time embedded systems, and wireless sensor networks. She authored or co-authored more than 160 technical papers in these areas. She is responsible for several international and national projects in the area of real-time embedded systems and networks.

Prof. Lo Bello was the recipient of the IES Early Career Award in 2008. She was the Chair of the IEEE Industrial Electronic Society Technical Committee on Factory Automation for two terms (2014–2015) and (2016–2017). She is an IES AdCom member and has been elected Officer of the IES, with the Secretary role, for the 2020-2021 term. She is the current Industrial Electronic Society representative within IEEE Women in Engineering and the founder of the Women in IES initiative.

Thilo Sauter (Fellow, IEEE) received the Dipl.-Ing. and Ph.D. degrees in electrical engineering from TU Wien, Vienna, Austria, in 1992 and 1999, respectively.

Until 2003, he led the Factory Communication Group, Institute of Computer Technology. From 2004 to 2013, he was the Founding Director of the Institute for Integrated Sensor Systems, Austrian Academy of Sciences. Since 2013, he has been with the Center for Integrated Sensor Systems, Danube University Krems, Krems an der Donau, Austria, and a tenured Associate Professor for automation technology with TU Wien since 2014. His expertise and research interests include embedded systems and integrated circuit design, smart sensors, and automation and sensor networks with a focus on real-time, security, interconnection, and integration issues relevant to cyber-physical systems and the Internet of Things in various application domains such as industrial and building automation, smart manufacturing, or smart grids.

Dr. Sauter is the Vice-President of the Austrian Association for Instrumentation, Automation, and Robotics, and Senior AdCom Member of the IES. He is author or coauthor of more than 300 scientific publications and has held leading positions in renowned IEEE conferences. He is the Vice President for Publications of the IES, past Editor-in-Chief of the IEEE INDUSTRIAL ELECTRONICS MAGAZINE, and an Associate Editor for IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS and IEEE SENSORS JOURNAL. Moreover, he has been involved in the standardization of industrial communication systems for more than 20 years. In 2014, he was elected IEEE Fellow for his contributions to synchronization and security in automation networks.