

# Guest Editorial

## Special Issue on Recent Advances in Petri Nets, Automata, and Discrete-Event Hybrid Systems

### I. INTRODUCTION

**R**ECENT years have witnessed the rapid development and deployment of cyber and computer technologies, thus highly influencing the design methodologies of discrete-event and hybrid systems, i.e., systems with discrete and mixed discrete-continuous states/inputs. Their prevalence can be found in almost all areas of human life, such as embedded software, automated manufacturing systems, work-flow management, logic controllers, communication protocols, robotics, transportation and mobility, military, smart buildings, etc. Given the criticality of such applications, such systems ought to be carefully modeled, thoroughly verified, and adequately analyzed.

### II. AIMS OF THIS SPECIAL ISSUE

The aim of this special issue is to highlight the recent advances in Petri nets, automata, and discrete-event hybrid systems. The editorial team has selected 18 high-quality papers from those accepted in 2018 and 2019 in the IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS: SYSTEMS for this special issue. In this editorial, the selected papers are split thematically into the three groups. The first one contains papers focused on the logical correctness. The second group is oriented on the aspects related to the modeling and complexity analysis, while the last one deals with the performance analysis and possible applications.

#### A. Correctness

Six papers selected in this special issue deal with the correctness aspects of systems. A formal methods-based approach to automatically construct and visualize system-level attack graphs is presented in Al Ghazo *et al.*, given the system components, their vulnerabilities, and connectivity. The approach is illustrated through application to a practical SCADA network. Correctness control of automated manufacturing systems described by Petri nets is the subject of the technique shown by Wang *et al.* The introduced robust control algorithm permits for deadlock avoidance.

The correctness control for automated manufacturing systems is also considered by two further papers. Feng *et al.* proposed a deadlock prevention algorithm for systems with a type of unreliable resources, by using general Petri nets.

Yue *et al.* focused on the properties that the controller with robustness must satisfy in deadlock-prone unreliable systems.

A cooperative monitoring process of engineering projects is presented in Xue *et al.* The process provides three different levels of project performance progress for different roles or stakeholders. Conditions for deriving stabilizing control for certain class of hybrid systems with delays is provided in the work by He *et al.*

#### B. Modeling and Complexity Analysis

The modeling and complexity analysis of the system is the objective of the next six selected papers. A modeling technique of flexible discrete-event systems is proposed by Grichi *et al.* Formal syntax and semantic for a novel meta-model of an object constraint language [called reconfigurable object constraint language (ROCL)] are introduced. The presented solution is applied to reconfigurable wireless sensor networks.

The formal verification of reconfigurable timed discrete-event systems is studied in Hafidi *et al.* In particular, a new method is proposed in order to ensure the correctness of these systems with a reduced cost (decreasing the verification time and memory requirement).

An approximate analysis algorithm for live and safe Petri nets is proposed by Karatkevich *et al.* In opposite to the traditional methods, their presented solution is bounded by a polynomial in the number of places and transitions of a net.

A dynamic data slice approach is considered by Wang *et al.* to analyze the vulnerabilities in e-commerce systems. The presented technique permits for the construction of dynamic data slices in polynomial time.

Effective state space analysis of systems specified by Petri nets is performed by Karoui *et al.* Their method pays special attention to the state explosion problem. Wang *et al.* focused on the behavior similarity of workflow nets. Based on the relation profile of a workflow net, a behavioral relation matrix can be constructed leading to complexity reduction of further analysis.

#### C. Performance Analysis and Applications

The last group contains papers oriented on the system performance analysis and application aspects. Six papers are included. A generalized backward strategy is proposed by Yang *et al.* to solve a transient scheduling problem. The presented idea utilizes Petri net theory, and it is illustrated

via industrial examples. Luo *et al.* proposed a chromosome representation and invent a novel deadlock-free scheduling algorithm. The technique is oriented to flexible assembly systems specified by Petri nets.

Distributed control of automated manufacturing systems is presented by Yang *et al.* Their method can be applied in the modeling of the large-scale automated systems. An approach to support emergency resource management is shown by Zeng *et al.*, by introducing a novel type of Petri net. A conflict-free model is constructed by using different resolution strategies.

Tran *et al.* employed reinforcement learning (Q-learning) to explore the relationship between actions and states allocated dynamically that allow the humanoid robot to trigger a reaction to avoid falling. The presented idea is used for fall detection and recovery perturbation during robot swinging. Wang *et al.* proposed a quadcopter control strategy based on deep reinforcement learning. The learning technique is based on a deterministic policy gradient algorithm. Their presented idea is evaluated in a flight simulator.

In conclusion, we observe that modeling, verification, and various applications of discrete-event and hybrid systems are the subject of many exciting investigations in recent years. The papers selected in this special issue have offered new ideas, methodologies, and applications that greatly advance the field of Petri nets, automata, and discrete-event hybrid systems. Our sincere hope is that this special issue will stimulate future cutting-edge research and development in this important field.

#### ACKNOWLEDGMENT

The Guest Editors would like to thank all the authors who have contributed their research papers that are selected into this Special Issue. They highly appreciate

the contribution of the reviewers for their constructive comments and suggestions. They would also like to thank Prof. Robert Kozma, Editor-in-Chief, for his excellent support and for giving them the great opportunity to organize this Special Issue.

REMIGIUSZ WISNIEWSKI, *Guest Editor*  
Institute of Electrical Engineering  
University of Zielona Góra  
65-246 Zielona Góra, Poland

MENGCHU ZHOU, *Guest Editor*  
Department of ECE  
New Jersey Institute of Technology  
Newark, NJ 07102 USA

LUIS GOMES, *Guest Editor*  
Departamento de Engenharia Electrotécnica e de  
Computadores  
NOVA University Lisbon  
2829-516 Caparica, Portugal

MARIA PIA FANTI, *Guest Editor*  
Department of Elettrotecnica ed Elettronica  
Polytechnic of Bari  
70125 Bari, Italy

RATNESH KUMAR, *Guest Editor*  
Department of Electrical and Computer Engineering  
Iowa State University  
Ames, IA 50011 USA



**Remigiusz Wisniewski** (Senior Member, IEEE) received the Doctoral degree in computer science from the University of Zielona Góra, Zielona Góra, Poland, in 2008, and the D.Sc. (Habilitation) degree in computer science from the Silesian University of Technology, Gliwice, Poland, in 2018.

He is the Head of the Division of Applied Informatics and Electronics, University of Zielona Góra, where he has been a Professor since 2019. From 2000 to 2003, he was with Aldec, Inc., Henderson, NV, USA, where he conducted specialized training for companies, such as Xilinx, San Jose, CA, USA, and Intel, Austin, TX, USA. In 2019, he was a Visiting Professor during the internship with the University of California at Berkeley, Berkeley, CA, USA. He has authored over 100 peer-reviewed research papers and books. His research interests include design and analysis of the control part of the cyber-physical systems, concurrent control systems, Petri nets, programmable devices, field programmable gate arrays (FPGAs), partial reconfiguration of FPGAs, perfect graph and hypergraph theories, and cryptography.

Prof. Wisniewski is an Associate Editor of the IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS: SYSTEMS and IEEE ACCESS, where he was awarded “Associate Editor of the Month” in July 2019. He is a member of IES and SMC societies and the IEEE IES Technical Committee on Industrial Informatics. He is a member of the Advisory Board at Polish Ministry of Science and Higher Education (“Industrial Doctorate” program). He is the Co-Founder and Coordinator of the research project Hippo: [www.hippo.iee.uz.zgora.pl](http://www.hippo.iee.uz.zgora.pl).



**MengChu Zhou** (Fellow, IEEE) received the B.S. degree in control engineering from the Nanjing University of Science and Technology, Nanjing, China, in 1983, the M.S. degree in automatic control from the Beijing Institute of Technology, Beijing, China, in 1986, and the Ph.D. degree in computer and systems engineering from Rensselaer Polytechnic Institute, Troy, NY, USA, in 1990.

In 1990, he joined the New Jersey Institute of Technology, Newark, NJ, USA, where he is currently a Distinguished Professor of Electrical and Computer Engineering. He has over 900 publications, including 12 books, over 600 journal papers (over 450 in IEEE TRANSACTIONS), 26 patents, and 29 book-chapters. His research interests are in Petri nets, intelligent automation, Internet of Things, big data, Web services, and intelligent transportation.

Dr. Zhou is a recipient of the Humboldt Research Award for U.S. Senior Scientists from Alexander von Humboldt Foundation, the Franklin V. Taylor Memorial Award, the Norbert Wiener Award from IEEE Systems, Man, and Cybernetics Society, and the Excellence in Research Prize and Medal from NJIT. He is the Founding Editor of IEEE Press Book Series on Systems Science and Engineering, the Editor-in-Chief of the IEEE/CAA JOURNAL OF AUTOMATICA SINICA, and an Associate Editor of the IEEE INTERNET OF THINGS JOURNAL, IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS, and IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS: SYSTEMS. He is a Life Member of the Chinese Association for Science and Technology, USA, and served as its President in 1999. He is a Fellow of the International Federation of Automatic Control, the American Association for the Advancement of Science, and the Chinese Association of Automation.



**Luis Gomes** (Senior Member, IEEE) received the Electrotech Engineering degree from the Technical University of Lisbon, Lisbon, Portugal, in 1981, and the Ph.D. degree in digital systems from University NOVA Lisbon, Lisbon, in 1997.

He is an Associate Professor with Habilitation with the Electrical and Computer Engineering Department, Faculty of Sciences and Technology, NOVA University Lisbon and a Researcher with UNINOVA Institute, Caparica, Portugal. From 1984 to 1987, he was with EID, a Portuguese medium enterprise, in the area of electronic system design, in the Research and Development Engineering Department. He was made an Honorary Professor with the Transilvania University of Brasov, Brasov, Romania, in 2007, as well as an Honorary Professor of Óbuda University, Budapest, Hungary, in 2014. He has author/coauthored more than 300 papers and chapters published in journals, books, and conference proceedings, as well as coauthor of one book and co-editor for three books. His main interests include the usage of Petri nets and other models of

concurrency, applied to reconfigurable and embedded systems co-design, and cyber-physical systems.

Dr. Gomes received the IEEE Industrial Electronics Society Anthony J. Hornfeck Service Award in 2016. He is currently serving/was recently serving as an Associate Editor for the IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, and *IEEE Industrial Electronics Magazine*, and also served as guest co-editor for several special sections on the referred IEEE TRANSACTIONS, as well as IEEE ACCESS.



**Maria Pia Fanti** (Fellow, IEEE) received the Laurea degree in electronic engineering from the University of Pisa, Pisa, Italy, in 1983.

She was a Visiting Researcher with the Rensselaer Polytechnic Institute of Troy, Troy, NY, USA, in 1999. Since 1983, she has been with the Department of Electrical and Information Engineering, Polytechnic of Bari, Bari, Italy, where she is currently a Full Professor of system and control engineering and the Chair of the Laboratory of Automation and Control. She has published more than 300 papers and two textbooks on her research topics. Her research interests include management and modeling of complex systems, such as transportation and logistic systems, discrete-event systems, Petri nets, consensus protocols, and fault detection.

Prof. Fanti was an Editor of the IEEE TRANSACTIONS ON AUTOMATION SCIENCE AND ENGINEERING. She is an Associate Editor of the IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS: SYSTEMS. She was a Member-at-large of the Board of Governors of the IEEE Systems, Man, and Cybernetics Society. She is member of the AdCom of the IEEE Robotics and Automaton Society and the Chair of the Technical Committee on Automation in Logistics of the IEEE Robotics and Automation Society. She was the General Chair of the 2011 IEEE Conference on Automation Science and Engineering, the 2017 IEEE International Conference on Service Operations and Logistics, and Informatics, and the 2019 Systems, Man, and Cybernetics Conference.



**Ratnesh Kumar** (Fellow, IEEE) received the B.Tech. degree in electrical engineering from the Indian Institute of Technology (IIT) Kanpur, Kanpur, India, in 1987, and the M.S. and Ph.D. degrees in electrical and computer engineering from the University of Texas (UT) at Austin, Austin, TX, USA, in 1989 and 1991, respectively.

He is a Ruth and Murray J. Harpole Professor with the Department of Electrical and Computer Engineering, Iowa State University, Ames, IA, USA, where he directs the ESSeNCE Lab (Embedded Software, Sensors, Networks, Cyberphysical, and Energy Lab). He held a faculty position with the University of Kentucky, Lexington, KY, USA, and also visiting positions with the University of Maryland, College Park, MD, USA; the Applied Research Laboratory, Pennsylvania State University, State College, PA, USA; NASA Ames, Mountain View, CA, USA; Idaho National Laboratory, Idaho Falls, ID, USA; United Technologies Research Center, East Hartford, CT, USA; General Electric Global Research, Niskayuna, NY, USA; and Wright Patterson

Air Force Research Laboratory, Wright-Patterson AFB, OH, USA.

Dr. Kumar was a recipient of the Gold Medals for the Best EE Undergrad, the Best EE Project, and the Best All Rounder from IIT Kanpur all in 1987, the Best Dissertation Award from UT Austin in 1991, the Best Paper Award from the IEEE TRANSACTIONS ON AUTOMATION SCIENCE AND ENGINEERING in 2016, and Keynote Speakership and best paper awards recipient from multiple conferences. He has received the D. R. Boylan Eminent Faculty Award for Research at Iowa State University. He was a Distinguished Lecturer of IEEE Control Systems Society. He is or has been an Editor for several journals and conferences, including IEEE, SIAM, ACM, IET, and MDPI. He is also a Fellow of AAAS.