Guest Editorial
Special Issue on the 2021 International Conference on Automation Science and Engineering

WE ARE pleased to present this Special Issue of IEEE TRANSACTIONS ON AUTOMATION SCIENCE AND ENGINEERING (TASE), which includes 11 extended articles selected from the technical program of the 17th International Conference on Automation Science and Engineering (CASE 2021). CASE 2021, held on August 23–27, 2021, at the Congress Center of Lyon, France, was primarily a face-to-face conference with online participation for those who could not travel to the beautiful and lively city of Lyon. CASE, as an offspring of TASE, is the flagship automation conference of the IEEE Robotics and Automation Society and constitutes the primary forum for cross-industry and multidisciplinary research in automation. Its goal is to provide a broad coverage and dissemination of foundational research in automation among researchers, academics, and practitioners. The theme of CASE 2021 was Data-Driven Automation.

With the constant expansion of CASE since 2005, successfully organizing CASE 2021 in the context of COVID-19 was a real challenge. In order to offer exciting real conference experiences, especially for young researchers, CASE 2021 was designed as a face-to-face conference. The CASE community was strongly mobilized with record submissions from over 40 countries including five workshop proposals, 33 special sessions, and 592 full papers among which 114 were joint RAL/CASE papers, 386 full papers, and 102 presentation-only papers.

The final program of CASE 2021 offered everything you can expect from a top international conference with:

- a rich scientific program of 435 papers, 336 full papers, and 99 presentation-only papers, spread over 11 parallel sessions, with a broad coverage and dissemination of academic and applied research in automation science and technology in all areas of our societies;
- keynote talks by world-class scholars and a wide industry panel with global enterprises on how data-driven automation has reshaped the research landscape;
- five workshops on hot topics in data-driven automation;
- technical tours of SNCF-Technicentre and Volvo Trucks;
- real conference experiences whatever your participation mode;
- and last, but definitely not least, face-to-face discussions and a rich social program in the city of Lyon.

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Four best paper awards were organized at IEEE CASE 2021: Best Conference Paper, Best Student Conference Paper, Best Application Paper, and Best Healthcare Automation Paper. The CASE 2021 Award Committee selected the finalists for each award, and the finalists were invited to present their papers live and to answer questions in special awards sessions. The presentations of the finalists and winners are available on the conference website: https://case2021.sciencesconf.org/.

This CASE 2021 Special Issue was by invitation only. Twenty-three invitations were sent to shortlisted papers identified by the independent award committee including all finalists and top-scored papers. All invited authors were expected to clarify the expansion/addition of contents in the Introduction of the TASE submission with respect to the CASE 2021 paper and their other relevant papers/submissions. Eighteen full papers were submitted and went through a peer-review process. Note that, in order to avoid any conflict of interest, papers from the key CASE 2021 organizing committee members were excluded from the award selection process and not invited for this Special Issue.

The final CASE 2021 Special Issue includes 11 articles classified into four groups: automation in production (four articles), additive manufacturing (two articles), service system operations (three articles), and distributed control (two articles).

Articles in the group on automation in production address the control of actuators and industrial robots for automatic production purposes. In [A1], Smith and MacCurdy present SoRoForge, a software tool that integrates major stages of pneumatic soft actuator design and fabrication. One key contribution is the automation of normally tedious or complex aspects of soft actuator design and fabrication: The specification of design geometry, the preparation of numerical simulation studies, and the physical realization of finished designs. Applications include soft manipulators on automated assembly lines, patient-specific biomedical implements, and food-handling equipment for easily bruised products. In [A2], Gao et al. address the fundamental skill in the production of pushing novel objects. This work proposes an innovative estimation of the center of mass (CoM) of an object by narrowing down its probable location with a deep learning model and Mason's voting theorem. Furthermore, it proposes the Zero Moment Two Edge Pushing (ZMTEP) method to translate a novel object without rotation to a goal pose that significantly outperforms competitive baseline methods. In [A3], Davoodi et al. develop a novel and safe control design approach that takes demonstrations provided by a human teacher to enable a robot to accomplish complex manipulation scenarios in dynamic environments. An overall task is divided into multiple simpler subtasks and, by collecting human demonstrations, the subtasks that require robot movement are modeled by probabilistic movement primitives (ProMPs). Strategies for modifying the ProMPs to avoid collisions with environmental obstacles are studied. A rule-based control technique is introduced for ProMP control using-state machines. Control barrier and Lyapunov functions are used to guide the system along a trajectory within the distribution defined by a ProMP while guaranteeing that the system state never leaves more than a desired distance from the distribution mean. The experimental studies demonstrate the efficacy of the approach and show that it can run in real time. In [A4], Zhu et al. propose a Deep Reinforcement Learning (DRL) based method for real-time assembly planning in robot-base prefabricated construction. Specifically, a reconfigurable simulator for assembly planning is developed based on a Building Information Model (BIM) and an open game engine, which could support the training and testing of various optimization methods. Furthermore, the assembly planning problem is modeled as a Markov Decision Process (MDP), and a set of DRL algorithms are developed and trained using the simulator. Finally, experimental case studies in four typical scenarios are conducted, and the performance of the proposed methods has been verified.

The second group addresses quality prediction and printer control in complex additive manufacturing. In [A5], Wang et al. propose a learning framework for the deviations of final product 3-D shapes from their intended designs including both smooth and non-smooth surfaces. The key idea is the association between the deviation profiles of smooth base shapes and those of non-smooth polyhedral shapes. The association, which is characterized by a novel 3-D cookie-cutter function, views polyhedral shapes as being carved out from smooth base shapes. The proposed learning framework reflects the decomposition into the smooth base shape formation and shape difference realization. The model-learning procedure first establishes the convolution model to capture the effects of layer-wise fabrication and sizes, and then estimates the 3-D cookie-cutter function to realize geometric differences between smooth and non-smooth shapes. A new Gaussian process model is proposed to consider the spatial correlation among neighboring regions within a 3-D shape and across different shapes. The case study demonstrates the feasibility and prospects of prescriptive learning of complex 3D shape deviations in AM and extension to broader engineering surface data. In [A6], Edoimioya and Okwudire address the model-based control of delta 3-D printers, by proposing an efficient framework to obtain accurate linear parameter-varying models of delta 3D printers at any position within their workspace from a few frequency response measurements. The dynamics are decomposed into two sub-models: 1) an experimentally identified sub-model containing decoupled vibration dynamics; and 2) an analytically derived sub-model containing coupled dynamics, which are combined into one using receptance coupling. It generalizes the framework by extending the analytical model of 2) to account for differing mass profiles and dynamic models of the printer's end-effector. Experiments demonstrate reasonably accurate predictions of the position-dependent dynamics of a commercial delta printer, augmented with a direct drive extruder, at various positions in its workspace.

Service system operations, including healthcare and data centers, are addressed by the three articles of the third group. In [A7], Zhang et al. address the issue of hospital bed planning in the context of the COVID-19 pandemic. A holistic modeling and analysis approach is proposed, with a system dynamics model to predict COVID-19 cases and a discrete-event simulation to evaluate hospital bed utilization, to support the hospital planning decisions. The model was trained using the public data from the JHU Coronavirus Resource Center and was validated using historical patient census data from the University of Florida Health Jacksonville, Jacksonville, FL, and public data from the Florida Department of Health (FDOH). Various experiments were conducted to investigate different control measures and the variants of the virus and their impact on disease transmission and, subsequently, the hospital planning needs. In [A8], Wang et al. address the improvement of patient throughput and proton beam utilization in a multiple-gantry proton therapy facility that shares a proton beam accelerator. To reduce the beam wait time while maximizing utilization, a simulation optimization gantry call-back control (SOGCC) method is proposed to determine the optimal time to call a patient back to the gantry so that beam request conflicts can be improved without sacrificing much beam utilization. The simulation experiment demonstrates how the variation of the setup time, beam treatment time, and transition time can undermine the performance of proton therapy systems, and the SOGCC method is able to account for the variation more efficiently. In [A9], Liu et al. study the operational issues related to the integration of decarbonized hydrogen-water-based energy (HWBE) system for the energy supply of Internet data centers (IDCs). The integrated planning-and-operation problem is formulated as a mixed-integer linear programming model to determine the optimal capacity of energy facilities. A hybrid physics-based and data-driven method is developed to accurately capture the electrical and thermal energy consumption characteristics and their coupling, which are the basis for the optimal planning of the HWBE system. Furthermore, a Benders decomposition-based reliability improvement algorithm is developed to enhance the operation reliability, where the problem is decomposed into a planning problem, with normal operation as the master problem, and an operational problem with IDC failures as the subproblem. The numerical results show that the developed HWBE system is energy-efficient with low carbon emission since the power usage efficiency of IDCs could be as low as 1.09 and the carbon emission could be reduced by 74.9% as compared with the electricity-driven IDC energy system.

Articles of the final group address distribution control with communication constraints. The article [A10] is motivated by a real-life case study of the Swalmen road tunnel in the Netherlands which is controlled by up to ten PLC controllers. This article discusses a method to distribute a synthesized supervisor for implementation on multiple physical controllers. Dependency structure matrices are used to determine a distribution of a system. The supervisor is then distributed accordingly, using an existing localization method. Communication delays between the distributed components of a supervisor may affect its behavior, due to changes in the order of events. Therefore, a new delay-robustness check is proposed where needed mutex locks are employed to make the distributed supervisor delay robust. The controller performance is analyzed and optimized through a parameter study and a mutex implementation evaluation. The method is demonstrated in the real-life case study by synthesizing, distributing, implementing, and validating a supervisor for the road tunnel. McMahon and Plaku [A11] address sea data collection using an autonomous underwater vehicle (AUV) and an unmanned surface vehicle (USV), where communications constraints must be maintained. A framework is developed, that includes an execution module and a multi-layered planner to enable the AUV to avoid collisions, maintain communication with the USV, and reach many of the discovered goals. The execution module enables the AUV to follow the planned motions, invoking the planner when new goals are discovered. To facilitate navigation, the planner constructs a 3-D roadmap that captures the connectivity of the environment by sampling and connecting waypoints in the free space. The high-level planning layer is based on an informed discrete search to find roadmap paths that satisfy the communication constraints and increase the sum of the goal rewards. The low-level layer uses sampling-based motion planning to expand a tree of feasible motions along these roadmap paths. Experiments demonstrate the efficiency of the approach to solve dynamic multi-goal motion-planning problems with communication constraints.

This Special Issue fully illustrates the cutting-edge research of data-driven automation presented at CASE 2021 with new methodologies and innovative ideas, as well as the variety of implementations across multiple industrial and service sectors including manufacturing, healthcare, construction, and transport.

We conclude this Editorial by thanking all the authors for their high-quality contributions. We are also indebted to all anonymous reviewers for their professional and valuable work that helped improve all manuscripts. Last but not least, we express our gratitude to the TRANSACTIONS' Editor-in-Chief, Prof. Yu Sun, and to the Editorial Assistant, Rebecca Hytowitz, for their invaluable support.

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APPENDIX: RELATED ARTICLES

[A1] L. Smith and R. MacCurdy, "SoRoForge: End-to-end soft actuator design," *IEEE Trans. Autom. Sci. Eng.*, early access, Feb. 8, 2023, doi: 10.1109/TASE.2023.3241866.

[A2] Z. Gao, A. Elibol, and N. Y. Chong, "Zero moment two edge pushing of novel objects with center of mass estimation," *IEEE Trans. Autom. Sci. Eng.*, early access, Sep. 29, 2022, doi: 10.1109/TASE.2022.3208739.

[A3] M. Davoodi, A. Iqbal, J. M. Cloud, W. J. Beksi, and N. R. Gans, "Rule-based safe probabilistic movement primitive control via control barrier functions," *IEEE Trans. Autom. Sci. Eng.*, early access, Nov. 7, 2022, doi: 10.1109/TASE.2022.3217468.

[A4] A. Zhu, T. Dai, G. Xu, P. Pauwels, B. de Vries, and M. Fang, "Deep reinforcement learning for real-time assembly planning in robot-based prefabricated construction," *IEEE Trans. Autom. Sci. Eng.*, early access, Jan. 18, 2023, doi: 10.1109/TASE.2023.3236805.

[A5] Y. Wang, C. Ruiz, and Q. Huang, "Learning and predicting shape deviations of smooth and non-smooth 3D geometries through mathematical decomposition of additive manufacturing," *IEEE Trans. Autom. Sci. Eng.*, early access, Jun. 2, 2022, doi: 10.1109/TASE.2022.3174228.

[A6] N. Edoimioya and C. E. Okwudire, "A generalized and efficient control-oriented modeling approach for vibration-prone delta 3D printers using receptance coupling," *IEEE Trans. Autom. Sci. Eng.*, early access, Aug. 9, 2022, doi: 10.1109/TASE.2022.3197057.

[A7] T. Zhang, Y. Lu, Y. Guan, X. Zhong, and T. Hogan, "Data-driven modeling and analysis for COVID-19 pandemic hospital beds planning," *IEEE Trans. Autom. Sci. Eng.*, early access, Nov. 29, 2022, doi: 10.1109/TASE.2022.3224171.

[A8] F. Wang, Y. Huang, and F. Ju, "Simulation optimization gantry call-back control method for proton therapy systems," *IEEE Trans. Autom. Sci. Eng.*, early access, Aug. 16, 2022, doi: 10.1109/TASE.2022.3198106.

[A9] J. Liu, Z. Xu, J. Wu, K. Liu, X. Sun, and X. Guan, "Optimal planning of internet data centers decarbonized by hydrogen-water-based energy systems," *IEEE Trans. Autom. Sci. Eng.*, early access, Aug. 27, 2022, doi: 10.1109/TASE.2022.3213672.

[A10] L. Moormann, R. H. J. Schouten, J. M. van de Mortel-Fronczak, W. J. Fokkink, and J. E. Rooda, "Synthesis and implementation of distributed supervisory controllers with communication delays," *IEEE Trans. Autom. Sci. Eng.*, early access, Mar. 28, 2023, doi: 10.1109/TASE.2023.3260442.

[A11] J. McMahon and E. Plaku, "Autonomous data collection with dynamic goals and communication constraints for marine vehicles," *IEEE Trans. Autom. Sci. Eng.*, early access, Nov. 1, 2022, doi: 10.1109/TASE.2022.3217678.

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