Control for smart systems: Applications, trends, and future challenges

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Cyber-physical systems (CPS) enable the physical world to merge with the virtual, leading to an Internet of things, data, and services. One example of CPS is an intelligent manufacturing system, where the machines can perform many work processes in the cyber and the physical domains, by communicating with their physical components and leveraging on the virtual counterparts. Beyond the manufacturing domain, CPS are enabling novel capabilities in different business and societal contexts, leading towards data-driven decisions and actions. Using sensors, the embedded systems monitor and collect data from physical processes, like steering of a vehicle, energy consumption or human health functions, thus leading to advanced control capabilities. Furthermore, the systems are networked, making the data globally available, whilst enhancing the possibilities for cooperative/collaborative processes.

Cyber-physical systems make it possible for software applications to directly interact with events in the physical world, for example to measure peaks in energy consumption or component degradation. Notwithstanding, the wide adoption of the word "smart" to represent or qualify certain types of systems did not provide a unified specification of the features that make a system smart. The scientific literature shows divergences when describing Smartness or Smart Systems. Some works consider that smartness is possible through the extensive use of ICT or digital capabilities, whilst others provide a more holistic view of the concept, considering that smartness is reached through the cooperation of several factors such as policies, economy, governance, education, individuals, technology, sustainability, etc., towards the improvement of a certain environment. These trends lead to an increasing number and diversity of “smart systems” that need to work together in the future enterprises and society.

The special section of this issue of Annual Reviews in Control, entitled “Control for Smart Systems: applications, trends and future challenges” is composed of extended versions of 6 selected best papers published in open invited tracks of the IFAC TC 5.1 “Manufacturing

Plant Control", TC 5.3 "Integration and Interoperability of Enterprise Systems" and TC 9.3 "Control for Smart Cities" at the IFAC INCOM 2021 Symposium, Budapest, Hungary.

The tremendous developments in theories and technologies in control for smart systems lead to a diversity of applications in various domains. **The first paper, entitled "Control for Smart Systems: Challenges and Trends in Smart Cities", by Qing-Shan Jiaa, Hervé Panetto, Marco Macchi, Silvia Siri, Georg Weichhart, and Zhanbo Xu**, explores the applications to various systems that are crucial for the future of smart cities, including enterprise and manufacturing systems, transportation systems, energy systems, and data centres. Beyond discussing the existing technological trends and the methodological approaches developed so far for managing and controlling such systems, the authors also provide visions on the future challenges for these systems in these various aspects.

The second paper, entitled "Towards smart production planning and control; a conceptual framework linking planning environment characteristics with the need for smart production planning and control" by Mina Rahmani, Anita Romsdal, Fabio Sgarbossa, Jan Ola Strandhagen, and Mathias Holm, deals with rapid advances in Industry 4.0 that have the potential to transform production planning and control (PPC) through the emerging concept of smart PPC. This paper provides a visionary perspective by addressing the gap in research on how the characteristics of a company's planning environment impact on the need for, and potential benefit of smart PPC. The authors posit that the potential of smart PPC to improve PPC performance increases with the complexity of the planning environment. A set of propositions is developed for how 12 product, market, and process variables impact on the need for smart PPC. These are operationalized into a conceptual framework which can be used as a tool by practitioners and academics to assess a company's need for smart PPC.

The third paper entitled "Hybrid-Augmented Intelligence in Predictive Maintenance with Digital Intelligent Assistants", by Stefan Wellsandt. Konstantin Klein, Karl Hribernik, Marco Lewandowski, Alexandros Bousdekis, Gregoris Mentzas, and Klaus-Dieter Thobendiscusses, introduces a novel approach to interact with predictive maintenance systems through Digital Intelligent Assistants (DIAs). Indeed, predictive maintenance systems are socio-technical systems where the interaction between maintenance personnel and the technical system is critical to achieving maintenance goals. Employees who use a predictive maintenance system should explore, modify, and verify their analysis and decision-making methods and rules. Conventional interaction modes via computer screens are problematic since they are often hard to understand, obtrusive, and unintuitive. DIAs provide fast, intuitive, and potentially hands-free access to information systems through voice-based interaction and cognitive assistance integrating human knowledge into the predictive maintenance process to create a hybrid intelligence system.

The evolution of artificial intelligent (AI) technologies have extremely accelerated in the last decade,and contributed significantly also to the development of Cyber-Physical Production Systems (CPPS). The need to analyse AI related risks and dangers became an urgent task as these technologies have a weak point; AI can transform the relations between humans, devices and society in an undefined, so far mostly unknown way and extent, generating important ethical, legal and standardisation issues. **The fourth paper entitled "From Ethics to Standards – an overview of AI Ethics in Cyber-Physical Production Systems", by István Mezgár, and József Váncza**, suggests a passage from resolving ethical AI issues to AI standards using AI frameworks to realize the "Ethics by Design" approach in case of CPPS.

The fifth paper, entitled "Explainable heat demand forecasting for the novel control strategies of District Heating Systems" by Milan Zdravković, Ivan Ćirić, and Marko Ignjatović, presents some insights on facilitating proactive District Heating Systems (DHS), often made based on the real-time ambient temperature. It discusses the predictive modelling techniques based on modern Artificial Intelligence (AI) architectures, namely the Deep Learning (DL)-based multivariate time-series forecasting. The paper evaluates state-of-the-art DL architectures for multivariate one-step and multi-step prediction based on Long-Short Term Memory (LSTM) approach, namely, stacked LSTM, bi-directional LSTM, encoder-decoder, and attention models.

The last paper, entitled "Dynamic Planner: Integrated Planning and Scheduling based on Digital Twins and Reinforcement Learning for Customized Production", by Zai Müller-Zhanga, Pablo Oliveira Antoninoa, and Thomas Kuhna, proposes a Dynamic Planner, an approach leveraging digital twins and Deep-Q-Network to plan processes and optimize workflows for simultaneous production of personalized products. The implementation of digital twins is based on Asset Administration Shells, a kind of standardized digital twin that enables unified data access and interoperability between distributed devices. Digital twins of products and resources provide real-time information of their physical entities for the Dynamic Planner to make decisions based on the current operation conditions.

The editors of this special section of Annual Reviews in Control would like to express their gratitude to the authors for their excellent contributions. We are also very grateful to all reviewers who have dedicated efforts in reviewing these papers, and for their valuable comments and suggestions that significantly improved the overall quality of the contributions. We hope that this special section will serve as a good reference for researchers, scientists, engineers, and academicians in the field of the smart systems.