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Theodor Borangiu · Damien Trentesaux · Paulo Leitão · Olivier Cardin · Laurent Joblot *Editors*

Service Oriented, Holonic and Multi-agent Manufacturing Systems for Industry of the Future

Proceedings of SOHOMA 2021

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Preface

This volume gathers the peer-reviewed papers presented at the 11th edition of the International Workshop on Service-oriented, Holonic and Multi-agent Manufacturing Systems for the Industry of the Future, SOHOMA'21, organized on 18–19 November 2021 by the Arts et Métiers Institute of Technology of Cluny, France, in collaboration with University Politehnica of Bucharest (the CIMR Research Centre in Computer Integrated Manufacturing and Robotics), Polytechnic University Hauts-de-France (the LAMIH Laboratory of Industrial and Human Automation Control, Mechanical Engineering and Computer Science) and Polytechnic Institute of Bragança (the CeDRI Research Centre in Digitalization and Intelligent Robotics).

The main objective of SOHOMA workshops is to foster innovation in smart and sustainable manufacturing and logistics systems and in this context to promote concepts, methods and solutions for the digital transformation of manufacturing through service orientation and agent-based control with distributed intelligence.

The theme of the SOHOMA'21 Workshop is "**Convergence of factory asset and process lifecycle with product lifecycles in Cyber-Physical System-based production**".

Cyber-physical system (CPS) technologies play the central role in the manufacturing vision for the future: the traditional automation pyramid (ISA95) is extended to include IT systems that are used outside the domain of process automation but have to be considered in an extended *product-factory* lifecycle perspective. This collaboration pyramid therefore includes: (i) the CPS-Automation pyramid which derives from ISA95, (ii) product lifecycle management (PLM) tools covering the design and engineering phases; customer relationship management (CRM) tools and human-systems integration principles and (iii) IoT solutions which enable to develop and improve services, usage and reuse/recycle of the products. This vision links thus together all existing (PLM, multi-agent system (MAS), manufacturing execution system (MES), constraint programming (CP) optimization, renterprise resource planning (ERP)) and under development (CPS, Industrial IoT (IIoT), fog- and cloud services, digital twins (DT), edge computing) factory control and management software tools and frameworks, whose data and information are relevant to create product-service centric, closed loop collaboration based on resource and infrastructure sharing in cloud networked enterprises.

In the *product lifecycle perspective*, both the virtual (design and engineering) and the physical parts of the product are considered. Products conceived and designed to be embedded with computing and reality awareness capabilities and thus to be "intelligent" both in their manufacturing and utilization phases are able to exchange information within and beyond the limit of the factory. These smart products relate to factory assets and processes in manufacturing value chains including design, planning, production supply and distribution networks and in after-sales services including maintenance, repair, upgrade and disassembly, providing new types of interactions such as collaborative demand and supply planning, product-centric control, customer orientation, lifecycle traceability and servitization.

In the factory lifecycle perspective, both the physical and digital parts are included. CPS technologies and CPS-based solutions will lead to an improved visibility across the value network giving an opportunity to configure it in the form of new business models at any level. This increasing visibility will foster the value network alignment with its customers' changing needs and optimization against different perspectives (quality, time to market, costs, sustainability goals, etc.). Thanks to the big amount of information made available, both small, medium and large enterprises will be able to proactively and timely respond to the evolving manufacturing ecosystem dynamics.

Cyber-physical systems take advantage from the integration of cloud-based and service-oriented architecture to deploy end-to-end support along both product lifecycle and factory lifecycles—asset health monitoring and maintenance, reality awareness, optimization and support to intelligent decision-making). In the factory lifecycle perspective, CPSs are able to interact with all the hierarchical layers of the automation pyramid—from field automation to enterprise resource planning (ERP)—and to empower the exchange of information across all the process and service stages, resulting in a better product-service development.

Transforming industry with intelligent end-to-end solutions and the shift to smart manufacturing are based on innovations in automation, robotics cloud services and the Industrial Internet of Things (IIoT). Introducing artificial intelligence (AI) and machine learning (ML) techniques in large-scale digital manufacturing control leads to greater productivity, increased safety and reduced costs.

The digitalization process of enterprises and the integration of smart shop floor devices and control software through secure communication caused an explosion in the data points available on field device and manufacturing execution system (MES) layers. The degree in which enterprises can capture value from processing these data and extract useful insights represents a differentiating factor to optimize production and join open, universal manufacturing structures. Machine learning and big data technologies have gained increased traction—being adopted initially for corner case scenarios and, as more data and computation power became available, also in critical areas of production planning and control. Cloud computing and servicers provide a robust platform for developing these solutions, lowering the cost of experimentation and implementation of various solutions.

The research of the SOHOMA scientific community is aligned to the actual trends and development priorities for CPS in the manufacturing and supply chain industries:

A. Future industrial systems will be conceived as cyber-physical systems that use strongly coupled virtual entities (software agents, holons or virtual twins) which represent (and are embedded in) physical components that sense, actuate, process, control, compute and communicate through several networks including the Internet in order to reach global goals—making products, controlling their quality, delivering services efficiently and safely. The drivers of industrial CPSs are resource and product virtualization and distribution of intelligence in IT systems that virtualize workloads through cloud services. MES virtualization reduces operational costs and improves flexibility, agility, reconfigurability and maintainability of the production system.
B. The factory data streams as well as the global MES functions will be mapped to specific workloads in the cloud defined in terms of activity scheduling, resource assignment and behaviour forecast; the latter incorporate AI and ML capabilities. The industrial sector is interested in deploying autonomous workloads to achieve higher productivity and better operational safety.
C. Autonomous workloads, supported by AI and other innovative technologies, are predicted to become the most pervasive workloads across the industrial sector.
D. Manufacturing as a Service (MaaS), which is based on new models of service-oriented, knowledge-based manufacturing systems optimized and reality-aware, virtualizing and encapsulating shop floor and MES workloads into cloud networked services, will also address "product design for open manufacturing", a vision of knowledge and infrastructure sharing in cloud networked enterprises.

This approach derives from the research performed in the last years in the scientific community SOHOMA, which uses recently developed key digital technologies—cloud and fog computing, digital twins, edge computing and IIoT, supervisory control and optimization, robotics, machine vision, additive machining, artificial intelligence and machine learning:

- Data mining and analysis of data collected during the utilization phase to design new product-service systems.
- CPS-enabled reconfiguration of automated manufacturing systems: (1) deployment of legacy production equipment and systems; (2) increasing autonomy and intelligence of existing machinery and robots; (3) adaptation through context awareness and reasoning aiming at making machinery and robots aware of their surroundings; (4) developing a multi-layered, decentralized control architectures in which resources can take autonomous decisions.
- Intelligent decision-making in cloud manufacturing through big data streaming and machine learning; combining data-driven digital twins for predictive situation-awareness with model-driven digital twins simulating the reality of interest faster than real time with software in the loop.

- Sharing of data/information from all the supply chain's elements to support continuous monitoring and automatic control of all the production phases while preserving security and confidentiality of data shared along the supply network.
- The adoption of IoT and CPS as enablers of product servitization allowing to track the product and services along the whole lifecycle and consequently enhance customers' satisfaction.
- Digital manufacturing on a shoestring—low cost digital solutions for SMEs.
- Service manufacturing which includes design for open manufacturing, optimization, maintenance, supply and distribution activities, all of them being offered in the "as a Service" option.
- Fostering the open and universal manufacturing enterprise—responsive to the X-as-a Service model, where X covers design, manufacturing, supply and distribution, and supports resource sharing and networking in the cloud.

Following the workshop's technical programme, the book is structured in eight parts that group a number of chapters reporting research results in the lines of perspective models of digital manufacturing control: smart, cloud, and universal manufacturing, of their implementing techniques, architectures and frameworks, and of humans integration in the CPS of the future complying to ethics norms of the artificial: *Part One*: Multi-agent and Holonic Approaches in Smart Manufacturing; *Part Two*: Digital Twins in Cyber-Physical Industrial Systems; *Part Three*: Human-Systems Integration in Cyber-Physical Systems; *Part Four*: Digital Manufacturing; *Part Five*: Industry of the Future: Ethics; *Part Six*: Reconfigurable Manufacturing Systems; *Part Seven*: Efficient and Intelligent Monitoring and Control of Industrial Systems; *Part Eight*: Intelligent Control for Sustainable and Efficient Supply Chain of the Future.

In the vision of the "Industry of the Future", cyber-physical systems are a breakthrough research area in manufacturing control and represent the new innovation frontier for accomplishing the EU2020 "smart everywhere" vision. Cloud and cloud analytics are defined as highest level layers of CPS in manufacturing, being referred in the majority of research priorities for cyber-physical manufacturing.

While research has mainly focussed on developments in automated systems, there has been a growing interest in the humans' role within Industry 4.0 environments. The challenges of mutual integration between humans and systems have also captured the interest of the SOHOMA community that has contributed to explore the role of humans in the industrial systems of the future, proposed and evaluated mechanisms for the effective integration and management of human factors in the design and decision-making processes of industrial systems and defined aspects of human well-being in industrial environments. In all these developments, strong attention has been paid to ethical and societal issues in the design, operating and maintenance of CPS. The increasing human presence and involvement in AI solutions for automated and autonomous systems have renewed the ethics challenges of human-centric industrial cyber-physical systems in sustainable factory automation. A framework is formulated in the SOHOMA'21 workshop for the primary profiles of the Operator 4.0 typology across transparency, equity, safety, accountability, privacy and trust and provides a level of completeness in which all ethics dimensions are closely intertwined.

SOHOMA 2021 research aligns to the CPS orientation in manufacturing by addressing key challenges: (i) *increasing autonomy and intelligence* of existing machinery and robots providing them with sensing and reasoning capabilities to recognize their environment, identify components of material flows, detect unforeseen events and gain flexibility in their assigned tasks; (ii) *adaptation through context awareness and reasoning*, aiming at making resources aware of their workplace environment so that they can perceive and obtain information on the unexpected and not programmed conditions and events, and adapt their behaviour in order to better handle them, while taking into account safety; (iii) *integration of humans* as Operator 4.0 in ethical cyber-physical production systems.

All these aspects are presented in this book, which we hope you will find useful reading.

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