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

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Preface

This volume gathers the peer-reviewed papers presented at the 12th edition of the International Workshop on Service-oriented, Holonic and Multi-Agent Manufacturing Systems for the Industry of the Future, SOHOMA'22, organized on 22–23 September 2022 by the CIMR Research Centre in Computer Integrated Manufacturing and Robotics of University Politehnica of Bucharest in collaboration with 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'22 Workshop is '**Virtualization—a multifaceted key enabler of Industry 4.0 from holonic to cloud manufacturing**'.

Virtualization in industrial control with computing and information-based system support signifies creating virtual versions of computer hardware platforms, computer network resources, industrial equipment or software control systems. There are two virtualization technologies currently available that allow creating virtual instances of various physical devices on different layers of digital environments including CPUs and process controllers, sensors, storage, networking, communication protocols and interfaces: (1) *digital twins* and (2) *agentification* of reality-reflecting class entities such as activities/processes, outcomes/products, facilities/resources and procedures/orders. The latter is either directly associated with the distribution of intelligence in heterarchical control systems or used as implementing framework of *holonic* orchestration.

The distribution of intelligence within industrial control systems and the need for collaborative decisions of strongly coupled shop floor entities—specific for Cyber-Physical Production Systems (CPPS)—led to the adoption of a new modelling approach for optimized and robust orchestration of batch processes: the *holonic control* paradigm. This approach is based on the virtualization of a set of abstract entities: *products* (reflecting the client's needs and value propositions), *resources* (technology, humans—reflecting the producer's profile, capabilities, skills) and *orders* (reflecting business solutions) that are modelled by autonomous holons collaborating in holarchies by means of their information counterparts—**intelligent agents** that are organized in dynamic clusters to reach a common, production-related goal.

At present, the *digital twin* concept evolved to a highly advanced modelling and simulation technology used for enhanced product and process design, event-driven resource maintenance and health monitoring, anomaly detection and intelligent manufacturing control with prediction of behaviours, production costs, reality-awareness and optimization. Modelling reality is done with two classes of digital twins (DT): *data driven* (with physical counterpart) that relies on distributed edge computing and storage of shop floor data in Industrial IoT frameworks and *model driven* (without physical twin)—a digital simulation for design and analysis. The multi-purpose character of digital twin virtualization in manufacturing derives from its main application areas:

- *Simulation with software in the loop*: a model-driven DT with control software operating in simulation exactly as it will be deployed; the virtual model is used to design equipment, tune parameters, validate layouts and compare performances in special conditions.
- *Synchronizing the virtual twin with its physical twin*: this type of DT is involved in all activities that imply the physical twin (e.g., shop floor resource, product with embedded intelligence) and provide control with situation awareness such as health monitoring or diagnostic.
- *Embedded simulation faster than real time*: a combination of a model-driven DT with physical, non-material twins of activity instances (e.g., individual product execution orders) allowing the latter to virtually execute much faster than real time (at computer speed) the intentions of the decision-makers (e.g., operation scheduling and allocation to resources, cost optimization, control tuning) on the twins of the resource instances, offering predictive situation awareness.

In cyber-physical systems for manufacturing, virtualization is performed on two layers: (1) shop floor entities (resources, products) and (2) MES (information system):

1. The set of workloads are directly connected to the *physical entities* that are virtualized by agents representing a resource or product; these are either *local individual workloads* of a physical device, e.g., resource monitoring, product routing, dispatching and tracking a production order, or *local collaborative workloads* of the shop floor, e.g., assigning jobs to resources for products in simultaneous execution.
2. The set of *global workloads* connected to *MES computing entities* are virtualized by expert or advisor agents acting as predictor of resource team utilization cost, optimization engine, system scheduler or anomaly detector; these are

workloads relative to the full production life cycle at the farthest horizon—the batch of ordered products.

Virtualization also represents the main enabling technology for *cloud computing applied to the industrial domain* regardless of the delivery method considered. The IT model of cloud computing (CC) is extended to services that orchestrate operational technology hardware and software elements (industrial controllers, application software) that monitor and control factory resources, products, processes and events. This dual cloud control and computing model (CCoC) is the real-time partition of the *cloud manufacturing* (CMfg) enterprise model mapped on its technical layer, and which:

- Transposes pools of factory resources (robots, machines, controllers, proprietary software) into on-demand making services.
- Enables pervasive, on-demand network access to a shared pool of configurable high-performance computing (HPC) resources—servers, storage and applications that can be rapidly provisioned and released as services to global MES workloads with minimal management.

The research of the SOHOMA scientific community is aligned to these technological developments that build up actual trends and development priorities for cyber-physical systems in the manufacturing, supply chain and logistics industries:

1. Sustainable Holonic Architectures (HCAs), able to optimize the production costs with reality-awareness, adaptability at environment changes and robustness at technical disturbances that ensure fault tolerance of the entire production system.
2. Reconfigurable Manufacturing Systems (RMS), designed for a) rapid adjustment of production capacity and functionality, in response to new circumstances, by rearrangement or change of their components: machines, robots and conveyors for the entire production system, new sensors and new controller algorithms; b) quick reaction to changing product demand, producing a new product on an existing system or integrating new process technology into existing manufacturing systems.
3. Mapping the factory data streams and global MES functions 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.
4. Developing the four key drivers to sustain the paradigm Logistics 4.0: data automation and transparency (end-to-end visibility over the supply chain, logistics control tower, optimization software); new production methods (robotized palletizing, stereovision-based picking); new methods of physical transport (driverless vehicles, autonomous pickers, drones); digital platforms (shared warehouse and transport capacity, cross-border platforms).

5. Manufacturing as a Service (MaaS)—new models of service-oriented, knowledge-based manufacturing systems, virtualizing and encapsulating shop floor and MES workloads into cloud networked services—will also address product design for 'open manufacturing' and the knowledge and infrastructure sharing in cloud collaborative manufacturing enterprises.
6. Developing Industry 4.0 models and frameworks using advanced technologies: robotics, additive manufacturing, augmented reality, extended digital modelling and simulation through digital twins, horizontal/vertical enterprise integration, cloud, cybersecurity, big data and analytics and the industrial Internet.

This integrated approach derives from the research performed in the last years by members of the scientific community SOHOMA, based on recently developed key digital and cyber-technologies: cloud and fog computing, digital twins, edge computing, optimization, cognitive robotics, intelligent image processing, machine vision, additive machining, artificial intelligence and machine learning, and ethical and societal models in future industrial systems: human–machine cooperation, human integration in cyber-physical systems, ethics of the artificial, humans in Industry 4.0 (I4.0), low-cost digital solutions for manufacturing:

- 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 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 implementing frameworks for digital supervision and control of manufacturing.
- 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 service-oriented architectures.
- 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, this book is structured into seven parts that group chapters reporting research results in topics related to service-oriented, holonic and multi-agent manufacturing systems for the industry of the future: *Part 1*: Applications of multi-agent and holonic systems in smart manufacturing; *Part 2*: Digital twins in industrial systems; *Part 3*: Factory—product life cycle value stream for Industry 4.0; *Part 4*: Education for Industry 4.0; *Part 5*: Performance, ethics and operations management in internal logistics 4.0; *Part 6*: Industry 4.0 technologies and low-cost digitization; and *Part 7*: Reconfigurable Manufacturing Systems.

Three main categories of changes in manufacturing foreshadowed by the transformations defined by Industry 4.0 are approached in the book: (1) The evolution of the manufacturing paradigm to mass customization, agility to frequent changes in product types and characteristics, and reconfigurability in response to unexpected environment and business conditions; the organizational perspective of this paradigm—with important implications in logistics—results from the relationship between products and manufacturing that will expand in future years from the 'many-to-one' production model (represented by integrated manufacturing) to the 'many-to-many' model with highly distributed production facilities (represented by open and universal manufacturing); (2) The use of new digital information, communication and control technologies such as holonic and multi-agent organization, digital twins, product intelligence, edge and cloud computing, machine learning integrated in IIoT and CPS architectures; (3) Human–system integration: Industry 4.0 developments integrate physical-, human- and software components leading to human CPS which is a system of interconnected systems (computers, devices, people) that interact in real time, working together to achieve the goals of production systems at environmental changes.

A number of workshop papers interpret and implement the special characteristics of the reference architecture model of the Industry 4.0 framework (RAMI4.0) reflecting the combination of life cycle and value stream with a hierarchically structured approach for the definition of I4.0 components. These papers highlight the interaction between four I4.0 structuring aspects: horizontal integration through value networks; vertical integration within a factory or shop floor; life cycle management and end-to-end engineering; human beings orchestrating the value stream. Proposals for I4.0 component implementation are made relative to the layers that define the structure of their virtual representation, the position and stage in the dual factory-product life cycles and the location of functionalities within the enterprise's hierarchy of information and control systems.

Cyber-physical systems are seen here as the backbone implementing infrastructure to realize Industry 4.0 compliant solutions that rely on a network of manufacturing components with cyber and physical counterparts, which have the ability of performing decentralized and autonomous decisions. CPS are combined with emergent digital technologies like Internet of Things, digital twin (a novel approach associated with the virtualization of production models, embedded in the design, virtual commissioning and optimization of processes and machines), big data, cloud control and computing, machine learning and cobots and are applied in the book's papers to different sectors, such as manufacturing, energy, logistics, construction and health care.

For the presented developments, RAMI4.0 serves as reference for engineering I4.0 systems, allowing designers to develop Industry 4.0 compliant solutions, based on the CPS approach, covering the hierarchy of industrial infrastructures and the life cycle/value stream of different production assets.

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

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