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Service Orientation in Holonic and Multi-Agent Manufacturing

Proceedings of SOHOMA 2018

Springer

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Preface

This volume gathers the peer-reviewed papers presented at the eighth edition of the International Workshop "Service Orientation in Holonic and Multi-agent Manufacturing—SOHOMA'18" organized on 11–12 June 2018 by the Universita degli Studi di Bergamo and Politecnico di Milano, Italy, in collaboration with University Politehnica of Bucharest, the CIMR Research Centre in Computer Integrated Manufacturing and Robotics, University of Valenciennes and Hainaut-Cambrésis, the LAMIH Laboratory of Industrial and Human Automation Control, Mechanical Engineering and Computer Science, and University of Lorraine, the CRAN Research Centre in Automation of Nancy.

The main objective of the SOHOMA'17 Workshop is to foster innovation in smart and sustainable manufacturing and logistics systems and in this context to promote concepts, methods and solutions addressing trends in service orientation of agent-based control technologies with distributed intelligence.

Following the workshop's technical program, the book is structured in six parts each one grouping a number of chapters describing research in the lines of the digital transformation in manufacturing based on resource virtualization, cloud services and intelligence distribution for production planning and control: *Part 1*: Cloud manufacturing: architectures, services and implementation in production control, *Part 2*: Human-centred design for adaptive manufacturing systems, *Part 3*: Service-oriented, multi-agent systems for holonic manufacturing control, *Part 4*: Digital transformation of the management in construction and transport, *Part 5*: Intelligent manufacturing control, supply chain and logistics, and *Part 6*: Cyber-Physical Production Systems and industrial Internet of things for Industry 4.0.

These six evolution lines have in common concepts, methodologies and implementing frameworks of new Service-oriented Information and Communication Technologies used for **Cyber-Physical Production Systems**, **Industrial Internet of Things**, **Cloud manufacturing**, extended digital process, resource and product modelling with **Digital Twins**, and pervasive shop floor device instrumenting and interconnecting with **Edge and Fog computing**.

The theme of the SOHOMA'18 Workshop in Bergamo, aligned with the strategic research line promoted by the IFAC TC 5.1 Committee "Manufacturing Plant Control", is *Digital transformation of manufacturing with agent-based control and service orientation of Internet-scale platforms*.

In the workshop's perspective, the digital transformation of manufacturing was placed in the general framework of the "Industry of the future" by including the actual vision and initiatives of developing architectures and core control technologies for the production processes based on a wide-ranging, Internet-scale platform linking scalably and interoperably technology providers, manufacturing system designers, shop floor systems, supply chains and service providers. This vision enables the emergence of a sustainable Internet economy for industrial production—strongly connected to the reality, robust at disturbances, agile relative to markets and customer-oriented.

Several drivers favour this digital transformation in industry; the focus is set on four of them in the SOHOMA'18 workshop:

- **Extended digital modelling** of processes, products and resources including description of physical laws and operating modes, history of events and maintenance, traceability reports during execution, KPI and performance monitoring, and shape representation. Digital 3D shape and adaptive machining models are increasingly used for part processing through material adding (3D printing) and removing;
- **Virtualization of shop floor devices** enabling a correct balance between local computing abilities (close to manufacturing resources and intelligent embedded products—"at the edge of the shop floor system") and global computing abilities (cloud MES platforms);
- **Evolution of cloud manufacturing** from public to private access, from centralized IaaS to distributed fog models, from that moves from production-oriented processes to customer- and service-oriented process networks;
- **Industrial Internet of Things** technology, seamlessly integrating smart connected objects in the cloud. This stimulates a product centric approach (during- and post-execution), where the product directly requests processing, maintenance and repair throughout its life cycle.

The 8th SOHOMA edition has put the focus especially on how the digital transformation, as the one advocated by the Industry 4.0 concepts, can improve the efficiency and resilience of manufacturing processes, the maintainability and quality of services performed by resources, and the efficiency and sustainability of manufacturing systems. Digital transformation relates to the interaction between the physical and informational worlds. It is realized via virtualization of products, processes and resources managed as services. The theoretical background lies in data and knowledge creation, management and utilization.

The 8th SOHOMA edition maintained the traditional focus on multi-agent systems (MAS) and holonic manufacturing execution systems (HMES)—which represent nowadays the computational and control architectures and implementing frameworks for the Cyber-Physical Production Systems (CPPS) connected to the world of interest through industrial Internet of things (IIoT) platforms. Service orientation of the production value chain was a topic of interest at the workshop, as it is a promising way to create the basis for agile, networked enterprises in which value is co-created with the customer's contribution.

The scientific event exposed the research developed in the last years by members of the scientific community SOHOMA and by other R&D groups from industry. These main research lines are as follows:

- Digital modelling techniques of manufacturing processes (machining, trajectory and surface generation, group technologies and CAD), information and control technologies (object orientation, agents, holons, nonlinear, constraint optimization, part description by image-extracted features…);
- Holonic architectures and multi-agent frameworks (distributing intelligence, semi-heterarchical topology with cloud MES and delegate MAS…);
- Intelligent products, orders and systems in industry (product intelligence, product-driven automation, machine learning, prediction and anomaly detection…);
- Service orientation of control and management in the manufacturing value chain (service-oriented architectures, servitization, product–service extensions, service-oriented agents, manufacturing services…);
- Problems of agility, flexibility, viability, resilience, reconfigurability, high availability and cyber-security in information processing and communication systems for industrial control;
- Cyber-Physical Production Systems and industrial IoT architectures and frameworks based on new technologies and tools (virtualization, embedding intelligence, edge computing with IoT gateways and aggregation nodes, fog computing and software-defined networks) for Industry 4.0.

The application space for these new developments proved to be very broad. The workshop SOHOMA'18 addressed all aspects of industrial systems management and control including:

- Control and management of manufacturing, supply chain, logistics, transportation, constructions and large-scale services;
- Production and after-sale services, maintenance and repair operations;
- Monitoring energy consumption and energy-aware control of industrial processes;
- Requirements and change management in the development of complex industrial projects.

The implementing space presented at SOHOMA'18 for these application classes showed the interaction between the physical and informational worlds with the integration of humans through agentification, big data processing, knowledge extraction and analytics, as well as virtualization of products, processes and resources managed as Web and cloud services.

A brief description of the book chapters follows.

Part 1 reports recent advances and ongoing research in *Cloud manufacturing: architectures, services and implementation in production control*. MES virtualization (the creation of a virtualized layer—the vMES) involves migration of MES workloads that were traditionally executed on physical machines to the data centre, specifically to the private cloud infrastructure as virtual workloads. From a virtualization perspective, two types of workloads were considered for the vMES: shop floor resources and intelligent products. New MES designs in the cloud and IIoT frameworks act in real time upon data collected on line data from shop floor devices. Data is reduced and aggregated through covariance of multiple metrics, and processed with machine learning algorithms to predict resource behaviours, with the aim of dynamically reconfiguring controls, minimizing global energy consumption at shop floor level, predicting the unexpected and assuring preventive maintenance. New cloud manufacturing (CMfg) functions use data streaming and analytics techniques. An architecture using data acquisition techniques and MapReduce algorithms to process the information streams in large-scale manufacturing systems, focusing on energy consumptions aggregated at various layers is presented. Once the information is aggregated in logical streams and consolidated based on relevant metadata, a neural network is trained in the cloud and used to learn historical patterns in data on each layer. A simulation study is included in this first part of the book, analysing cloud-based additive manufacturing as a strategy for product variety. Two test cases are conducted using discrete event simulations in two production systems: additive manufacturing (AM) and rapid tooling, given the same economic conditions. The benefit observed in AM is the immunity to product variety, and the drawback is the limitation of processing large volumes. Another paper proposes a detailed architecture for cloud-based production Internet. The novelty of this proposal is manifold: (i) it applies distributed and condition-based controlling of inter-organizational operations; (ii) it exploits mechanisms of ecosystemic homeostasis; (iii) it considers evolutionary mechanisms both for firms and internal services; (iv) it exploits novel forms of demand representation. The fourth contribution to this part describes a method of determining the status of photovoltaic panels (SP) and estimating its output; SPs are components of power microgrids, which are connected to a power smart grid (SG). Using the IoT functionalities for data transmission, environmental data and information about the power output of every photovoltaic panel are sent to the cloud, where they are processed and stored. Finally, the technological advances which are at the basis of Industry 4.0 are reported in this first part of the book, in order to assess the impacts of implementing such technologies in manufacturing, transforming traditional factories into smart factories.

Part 2 includes papers devoted to the theme of *Human-centred design for adaptive manufacturing systems*. This part of the book includes the reports of research works that propose human-centred design approaches of manufacturing control and evaluate related challenges using new social and environmental metrics throughout life cycle. The authors' contributions refer to social lifecycle assessment and adaptive manufacturing systems, human-centred design for intelligent manufacturing systems, computers in the human interaction loop and human-in-loop control, cooperative approaches to manage self-organized systems and interactive human–computer scheduling approaches. It is shown that human–machine system approaches encourage the cooperation between humans and complex artificial systems to react to unexpected events and to ensure an efficient supervision. The use of the cognitive work analysis (CWA) approach is then proposed to ensure efficient cooperation between the human and a self-organized production system. Two architectures for the integration of human workers as resource holons in holonic manufacturing systems are presented. The architectures form part of a holonic reference architecture (based on PROSA) and are implemented using the JADE multi-agent programming environment. The two architectures are called interface holon architecture (IHA) and worker holon architecture (WHA). With the IHA, a fixed interface at a workstation is represented by an agent in the MAS and the workers are managed by a human. With the WHA, every worker is directly represented in the MAS using a mobile interface, and workers are managed by an additional staff agent called "manager agent".

Part 3 is dedicated to *Service-Oriented, Multi-agent Systems for Holonic Manufacturing Control*. The Multi-agent Systems (MAS) computer science paradigm is intensively used to model, design and implement decentralized systems. In recent years, this technology, which was mainly associated to software development, has been used in the control of decentralized production systems. This concept, referred to as resource agentification, associates software agents to physical entities in order to simplify the access operations which are now seen as services in a framework with distributed intelligence. In the case of a manufacturing system, services are offered by resources and requested by products. In this section, a generic architecture for data collecting and intelligent processing at the edge of cloud-based control systems is presented; the data is transferred and aggregated in centralized cloud layers of CPPS. An example of such layer is the MES control layer implemented in a private cloud platform with IaaS model. The collected data is sent with selective timing to the cloud system for further high-level processing: computing the covariance of multiple metrics monitored for knowledge extraction, data analytics, machine learning (prediction, detecting anomalies) and making intelligent decisions (control optimization). In order to support multiple communication protocols and adapt the information generated by sensors/resources to user requirements, the concept of IoT gateway was extended in the present research to the aggregation node one. A model-driven approach for automated generation of service-oriented holonic manufacturing systems (SoHMS) is presented in this part of the book. A multi-agent perspective of the cooperation between smart manufacturing scheduling systems and energy providers is offered in a multi-agent approach to solve energy-aware production scheduling and re-scheduling systems. The approach is the hybrid combining of a predictive and reactive phase while taking into account sustainability; it is generic, suitable to smart grid infrastructure and can be applied to different real manufacturing problems. Another chapter of the book proposes a hybrid modelling approach based on agents describing a system's dynamics for the analysis and redesign of industrial entities; this model can be applied as a generic framework to different economic sectors including manufacturing, energy systems and agriculture.

Part 4 includes chapters in which recent research in the area of *Digital transformation of the management in construction and transport* is reported. The sector of Architecture, Engineering and Construction (AEC) is currently evolving towards the digital transformation: Building Information Modelling and Management (BIM) are spreading fast in building companies, thus reducing the building design cost and time. While BIM mainly focuses on the design phase, the Internet of things and the new paradigm of Industry 4.0 are additional opportunities for actors of the building sector to improve their products, processes and services in various phases of the building life cycle. The obvious linkage between the real world and the virtual world provided by the CPPS allows designing new data management architectures and innovative management strategies. In the context of process industrialization, one challenging issue is the transformation of design data into manufacturing data. One article in this part of the book proposes the automatic transformation from engineering bills of material (e-BOM) to manufacturing (m-BOM) ones based on routing sheets and resource availability. Another article describes the new disruption management strategy of "Dynamic Postponement", treated as an agent-based system. Simulation-based optimization based on genetic algorithm is used to determine the optimal balance between on/off-site work in constructions to maximise performance. The adoption of an innovative and progressive approach towards servitization by the European rolling stock manufacturing industry is treated in one chapter of this book part. It is shown that beyond technological developments (e.g. big data and artificial intelligence-based technologies), there is a number of current demand trends driving servitization in the rolling stock industry. This is because customer's requirements are changing from demanding just trains to demanding "trains as a service", with high expectations about the levels of availability and reliability. In another chapter, the authors define a new approach with a set of specifications on the supervision and decision support system (DSS) for effective condition-based maintenance (CBM) of a fleet of trains assimilated with cyber-physical systems. The fleets of intelligent CPS are embedded with intelligent processing architectures that communicate and exchange informations. An intelligent virtual agent is embedded in the supervision and DSS to allow the human supervisor to communicate with all intelligent CPSs in the fleet. The tabu search robustness for cross-dock and PI-hub scheduling under possible internal transportation breakdowns is further investigated; a tabu search meta-heuristic is proposed to solve the truck scheduling problem for both the classical cross-dock and the PI-hub with the objective to minimize the total tardiness of both inbound and outbound trucks.

Part 5 groups papers reporting research in *Intelligent Manufacturing Control, Supply Chain and Logistics*. An implementation solution for control redundancy to ensure the continued operation of manufacturing control system in the event of potential faults is described; the solution uses the built-in features of Erlang and its Open Telekom Platform (OTP) library for implementing standby controller redundancy for improved availability in manufacturing stations. The Erlang-based solution uses the failover and takeover mechanism of distributed OTP applications to detect controller faults and initiate controller changeover. The scheduling problem in manufacturing with high rework rates represents an issue for which hybrid manufacturing control combining centralized global optimization with proactive distributed decision making, based on analytic hierarchical process (AHP) method in case of heavy risk of non-quality prediction is proposed. The contribution to this research is the idea to embed each product in an instance of a quality prediction neural network model. To prevent non-quality, the risk prediction process allows to dynamically performing a local re-scheduling under certain conditions to be determined. If the neural network determines that the risk is over a threshold for the next batch to manufacture, then the system enters a collective decision-making process with the other batches present in the queue of the workstation. The goal of this negotiation is to determine which available batch in the queue must be the next one to be executed. The decision can be taken with respect to different criteria, for example the risk of non-quality, the due date of the products, the balance between the different product family flows, the setup time implied by the batch change or the system nervousness (the number of schedule alterations created by swapping batches). Legislation initiatives, models and real systems implementations of reverse supply chains (RSC) in industry are reviewed in a chapter. RSC activities consist of retrieving used products from customers for the purpose of disposal or reuse. End-of-life (EOL) products are collected and transported to collection centres, where they are stored in view of disassembly operations. The disassembled components are sorted and categorized into different quality subassemblies, reusable or non-reusable parts, residues, recyclable materials and both hazardous and non-hazardous disposable components. Each category of item is kept in its inventory until it is transferred to its corresponding end-of-life option. In a chapter of this part, a bi-objective credibility-based fuzzy mathematical programing model is developed to design a location-pricing problem in closed-loop supply chain with a single product under uncertainty. This problem aims at maximizing the total supply chain profit by determining the optimal number of facility location, collection and distribution centers (CDCs), the assignment of customer zones to the CDCs and the CDCs to the plants, the price of the new product and the incentive value of the returned product that should be offered for the used product.

Part 6 includes the contributions to the theory, modelling and architectural design of *Cyber-Physical Production Systems and Industrial Internet of Things for Industry 4.0*. One first article analyses cyber-physical resource scheduling in the context of industrial Internet of things operations. This research work proposes a model for the manufacturing operations in an IIoT environment, where cyber-physical resources participate in a decentralized work scheduling process.

Through the exchange of physical work-in-process and order information, the cyber-physical resources accomplish a common set of goals for the IIoT system, despite induced failures or delays at the processing resource and computational network levels. Holonic scheduling techniques are employed at the IIoT level, with part order, cyber-physical resource and data network holon entities. The cyber-resource holons perform processing operations and collect and process actual sensor data, while their operations are simulated in the cloud for prediction and quality. The data network between remote processing locations is modelled as a software-defined network (SDN), with the control level working as the data network holon computational unit. A key enabler for the advances associated with CPPSs is the concept of a "digital twin"—the cyber representation of the physical twin—which is a manufacturing cell in a chapter of this book final part. This paper presents the architecture for such a digital twin that enables exchanging data and information between a remote emulation or simulation and the physical twin. The architecture comprises different layers, including a local data layer (e.g. OPC UA or databases local to the plant), an IoT gateway layer that relays information between the physical world and cyberspace, a cloud-based databases and a layer containing emulations and simulations. A paper in this book part applies Industry 4.0 characteristics to service companies, exemplifying them on the case of the French postal service. Finally, a research work included in the book's sixth part proposes an approach to enhance the 3C traditional CPS architecture by introducing the main interfacing elements, i.e. connectors, protocols and sub-elements, e.g. human, cyber and physical parts. Besides, the adaptation of sub-interfacing elements improves the standardization level of human, cyber and physical components for Industry 4.0.

The research works reported in this book suggest that the most natural solutions for the digital transformation of manufacturing and establishment of the cyber world are to virtualize shop floor devices (e.g. resources, products and orders) and use virtualized cloud services, or the newer edge and fog computing solutions. Recent research applied to industry emphasizes the need for securing the dual cyber-physical space. Inter-enterprise data networks are modelled here having SDN characteristics, such that manufacturing data packets are under a centralized logical control reducing the likelihood of data theft, and network delay or failure.

The rapid digitalization and smart integration of shop floor devices and control software systems caused an explosion in the data points available in large-scale manufacturing systems. The degree at which enterprises are able to capture value from processing this data and to extract useful insights from it represents a differentiating factor on short- and medium-term development and optimization of the processes that drive the manufacturing operations.

This consideration reinforces the necessity to bring closer the reality-reflecting part and the decision-making part of manufacturing control architectures. The research presented in this book assessed reference models and architectures (industrial IoT models, the cloud manufacturing models, production planning models, etc.) while focusing on their world of interest. The analysis established at which degree reality is reflected within these models and architectures, bringing into discussion the need to bring closer the information processing aspects from the real-world aspects. This implies, on one hand, intensive use of digital twins—models of processes, resources and products with extended behavioural and operating descriptions in space and time—and, on the other hand, the use of machine learning for knowledge and information extraction, prediction and anomaly detection at aggregated level, e.g., in the cloud MES for optimized decision making.

All these aspects are discussed in the present book, which we hope you will find useful reading.

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