

# Preface

This volume gathers the peer reviewed papers which were presented at the fifth edition of the International Workshop “Service Orientation in Holonic and Multi-agent Manufacturing—SOHOMA’15” organized on 5–6 November 2015 by the Institute for Manufacturing (IfM) of the University of Cambridge, UK in collaboration with the CIMR Research Centre in Computer Integrated Manufacturing and Robotics of the University Politehnica of Bucharest, Romania, the LAMIH Laboratory of Industrial and Human Automation Control, Mechanical Engineering and Computer Science of the University of Valenciennes and Hainaut-Cambrésis, France and the CRAN Research Centre for Automatic Control, Nancy of the University of Lorraine, France.

SOHOMA scientific events have been organized since 2011 in the framework of the European project ERRIC, managed by faculty of Automatic Control and Computer Science within the University Politehnica of Bucharest.

The book is structured in seven parts, each one grouping a number of chapters describing research in actual domains of the digital transformation in manufacturing and trends in future manufacturing control: Part I: Applications of Intelligent Products, Part II: Recent Advances in Control of Physical Internet and Interconnected Logistics, Part III: Sustainability Issues in Intelligent Manufacturing Systems, Part IV: Holonic and Multi-Agent System Design for Industry and Services, Part V: Service Oriented Enterprise Management and Control, Part VI: Cloud and Computing-Oriented Manufacturing, Part VII: Smart Grids and Wireless Sensor Networks.

These seven evolution lines have in common concepts, methodologies and implementing solutions for the *Digital Transformation of Manufacturing (DTM)*.

The Digital Transformation of Manufacturing is the actual vision and initiative about developing the overall architecture and core technologies to establish a comprehensive, Internet-scale platform for networked production that will encapsulate the right abstractions to link effectively and scalably the various stakeholders (product firms, manufacturing plants, material and component providers,

technology and key services providers) to enable the emergence of a feasible and sustainable Internet economy for industrial production.

For the manufacturing domain, the digital transformation is based on the following:

1. **Instrumenting** manufacturing resources (machines, robots, AGVs, ASRSs, products carriers, buffers, a.o.) and environment (workplaces, material flow, tooling, a.o.) which allows: product traceability, production tracking, evaluation of resources' status and quality of services, preventive maintenance...
2. **Interconnecting** orders, products/components/materials, resources in a *service-oriented* approach using multiple communication technologies: wireless, broadband Internet, mobile applications.
3. **Intelligent, distributed control** of production by:
  - *New controls* based on ICT convergence in automation, robotics, vision, multi-agent control, holonic organization; the new controls enable the **smart factory**.
  - *New operations* based on product- and process modelling and simulation. **Ontologies** are used as a “common vocabulary” to provide semantic descriptions/abstract models of the manufacturing domain: *core ontology*—modelling of assembly processes (resources, jobs, dependencies, a.o.); *scene ontology*—modelling flow of products; *events ontology*—modelling various expected/unexpected events and disruptions; these models and knowledge representation enable the **digital factory**.
  - *Novel management* of complex manufacturing value chains (production, supply, sales, delivery, etc.) for networked, **virtual factories**: (a) across manufacturing sites: logistics, material flows; (b) across the product life cycle.

Research in the domain of DTM is determined by the last decades' trend in the goods market towards highly customized products and shorter product life cycles. Such trend is expected to rise in the near future, forcing thus companies to an exhaustive search for achieving responsiveness, flexibility, reduction of costs and increased productivity in their production systems, in order to stay competitive in such new and constantly changing environment. In addition, there is a shift from pure goods dominant logic to service dominant logic which led to service orientation in manufacturing and orienting the design, execution and utilization of the physical product as vehicle for delivering generic or specific services related to that product (in “Product-Service Systems”).

How this new vision on digital transformation of manufacturing is achieved? Reaching the above objectives require solutions providing:

- Dynamic reconfigurability of production (re-assigning resource teams, re-planning batches, rescheduling processes) to allow “agile business” in manufacturing;
- Robustness at technical disturbances;

- Efficient execution of production (in terms of cost, productivity, balanced usage of resources);
- Sustainability of manufacturing (proper asset management, controlled power consumption, quality assurance);
- Integration of manufacturing enterprise processes:
  - Vertical integration of the business, MES and shop-floor layers of the manufacturing enterprise;
  - Horizontal integration through value networks.

The solutions adopted for achieving digital transformation of manufacturing are as follows:

- A. **Distributed Intelligent Control** at manufacturing execution system (MES) and shop-floor levels, based on ICT frameworks: control distributed over autonomous intelligent units (agents), multi-agent systems (MAS), holonic organization of manufacturing.
- B. **Service-Oriented Architecture** (SOA), more and more used as an implementation mean for MAS. SOA represents a technical architecture, a business modelling concept, an integration source and a new way of viewing units of automation within the enterprise. Integration of interoperable business and process information systems at enterprise level are feasible by considering the customized product as “active controller” of the enterprise resources—thus providing consistency between the material and informational flows within the production enterprise. Service orientation in the manufacturing domain is not limited to just Web services, or technology and technical infrastructure either; instead, it reflects a new way of thinking about processes and resources that reinforce the value of commoditization, reuse, semantics and information, and create business value.
- C. **Manufacturing Service Bus** (MSB 2.0) integration model: an adaptation of the enterprise service bus (ESB) technology for manufacturing enterprises; it introduces the principle of bus communication between the manufacturing layers acting an intermediary for data flows and assures loose coupling of manufacturing modules.

New developments are induced by digital transformation of manufacturing; they are described in this book:

*Cloud manufacturing* (CMfg), one of these new lines, has the potential to move from production-oriented manufacturing processes to customer- and service-oriented manufacturing process networks, e.g. by modelling single manufacturing assets as services in a similar way as SaaS or PaaS software service solutions. The cloud manufacturing paradigm moves the intelligent manufacturing system (IMS) vision one step further since it provides service-oriented networked product development models in which service consumers are enabled to configure, select and use customized product realization resources and services, ranging from computer-aided engineering software to reconfigurable manufacturing systems.

To achieve high levels of productivity growth and agility to market changes, manufacturers will need to leverage *Big Data* sets to drive efficiency across the networked enterprise. There is need for a framework allowing the development of *Manufacturing Cyber Physical Systems* (MCPS) that include capabilities for complex event processing and big data analytics, which are expected to move the manufacturing domain closer towards digital- and cloud manufacturing within the *Contextual Enterprise*.

A brief description of the book chapters follows.

**Part I** reports recent advances and ongoing research in developing *Applications of Intelligent Products*. The intelligent product (IP) model was introduced as a means of motivating supply chains in which products or orders were central as opposed to the organizations that stored or delivered them. This notion of a physical product influencing its own movement through the supply chain is enabled by the evolution of low-cost RFID systems which promise low-cost connection between physical goods and networked information environments. The characteristics of an IP and the fundamental ideas behind it can also be found in other emerging technological topics, such as smart objects, objects in autonomous logistics and the Internet of Things. In manufacturing, the intelligent product is the driver for heterarchical operations scheduling and resource allocation. The IP is one member of the set of Active Order Holons, which together compose the delegate MAS performing collaborative decisions concerning the product's route. This solution allows implementing "product-driven automation" in a completely decentralized mode. This section includes papers describing how the IP concept is used in: hybrid control of radiopharmaceuticals production, improving productivity of construction projects, automation of repair of appliances and necessary information requirements, and End-of-Life information management for a circular economy.

**Part II** groups papers devoted to *Physical Internet Simulation, Modelling and Control*. The current instrumenting and interconnecting facilities and the availability of individual information in open-loop supply chains enable new organizations like Physical Internet (PI). One of the key concepts of the PI relies on using standardized containers that are the fundamental unit loads. Physical goods are not directly manipulated by the PI but are encapsulated in standardized containers, called PI-containers. The PI relies on a distributed multi-segment intermodal network. By analogy with the Digital Internet transmitting data packets rather than information/files, the PI-containers constitute the material flow among the different nodes of the PI network. The design of cross-docking hub (in analogy with digital internet, can be seen as a router), allowing the quick, flexible and synchronized transfer of the PI-containers, is essential for the successful development of the Physical Internet. Different types of hubs, denoted PI-hubs, are considered (e.g. road to rail, road to road, ship to rail). The aim of the innovative PI concept is to solve unsustainability present in current supply chains and logistics systems. Papers discuss: automated handling, storage, routing and traceability in the PI context combining spontaneous networking offered by WSN with container virtualization; frameworks for instrumenting PI in a collective of "smart" PI-containers in

interaction; crowdsourcing solutions to last mile delivery in e-commerce environment; open tracing container and IoT in automotive and transport fields.

**Part III** analyses *Sustainability Issues in Intelligent Manufacturing Systems*. Two perspectives are considered: (1) The needs to add sustainability to efficiency performance in IMS design, and (2) Approaching these needs using concepts from IMS engineering methods in the context of sustainable manufacturing systems design. Directions indicated by the reported research: (1) Go-green holons as green artefact that help the system designer to implement solutions for sustainable IMS, and (2) Defining a set of guidelines that enforce system engineers to think about their main designs choices of the sustainable parameters to be taken into account in the new type of IMS. Key requirements for resilient production systems are also developed by establishing the links between production disruption and the required resilient control and tracking capabilities in production systems. A semantic model of requirements in large and complex manufacturing systems, based on business concepts and modelled with resource description framework (RDF), is included in this book section. Related to sustainability, Part III also analyses how the human operator is integrated in the IMS's control architecture. "Human-in-the-loop" Intelligent Manufacturing Control Systems consider the intervention of humans (typically, information providing, decision-making or direct action on physical components) during the intelligent control of any functions relevant to the operational level of manufacturing, such as scheduling, maintenance, monitoring, supply, etc. With a human-centred design approach in IMS, human resources can be assisted by recent ICT tools helping them detecting in advance problems, propose efficient solutions and take decision and action.

**Part IV** reports recent advances in *Holonic and Multi-Agent System Design for Industry and Services*. Nowadays, industry is seeking for models and methods that are not only able to provide efficient global batch production performance, but also reactively facing a growing set of unpredicted events. One important research activity in the field focuses on holonic and multi-agent control systems that integrate predictive, proactive and reactive mechanisms into agents/holons. The holonic approach is the main engine for the digital transformation of manufacturing at manufacturing execution system (MES) middle layer and shop-floor production control layer level in what concerns "Distribution" and "Intelligence". The holonic manufacturing paradigm is based on defining a main set of assets: resources (technology, humans—reflecting the producer's profile, capabilities, skills), orders (reflecting the business solutions) and products (reflecting the client's needs, value propositions)—represented by holons communicating and collaborating in holarchies to reach a common goal—expressed by orders. As

$$[\text{Holon}] \leftarrow [\text{Physical Asset}] + [\text{Agent} = \text{Information counterpart}],$$

it becomes possible to solve at informational level all specific activities of the physical layer: mixed batch planning, product scheduling, resource allocation, inventory update, product routing, execution, packaging, tracking and quality control:

- Triggered by real-time events gathered from the manufacturing structure processes and devices;
- Controlled in real time, with orchestration and choreography assured by SOA in standard, secure mode.

Thus, the holarchy created by the holons defined for any holonic manufacturing system (HMS) acts as a “Physical Multi-agent System—PMAS”, transposing in the physical realm the inherent distribution induced by an agent implementation framework, according to defined manufacturing ontologies.

The demand for production systems running in complex and disturbed environments requires considering new paradigms and technologies that provide flexibility, robustness, agility and responsiveness. Holonic systems are by definition targeting challenges that include coping with the heterogeneous nature of industrial systems and their online interactive nature in combination with competitive pressures. Multi-agent systems is a suitable approach to address these challenges by offering an alternative way to design control systems, based on the decentralization of control functions over distributed autonomous and cooperative entities. Chapters of this Part IV describe: coordinating mechanisms in HMS; automatic diagnostic methods to increase dependability by using model-checking at runtime; interfacing BDI agent systems with geometric reasoning in robotized manufacturing; nervousness control mechanisms for semi-heterarchical MES; and applications of HMS in industry.

**Part V** groups papers dealing with *Service Oriented Enterprise Management and Control*. Integrating the concepts of services into HMS gives rise to a new type of systems: service-oriented holonic manufacturing systems (SoHMS). SoHMS is underpinned by the use of a structure based on repeatability and reusability of manufacturing operations. Process families are formed by a collection of process modules representing manufacturing operations. By adopting the principles of SOA into HMS, such manufacturing operations can be standardized into manufacturing services (MServices) possessing a proper identification and description. Thus, the service becomes the main element of negotiation and exchange among holons. Conceiving manufacturing services and manufacturing processes specifications allows the HMS’s control architecture to explore manufacturing flexibility at process level with the decomposition and encapsulation of processes.

Following the IT-based approach which defines a service as “a single activity or a series of activities of a more or less intangible nature that normally takes place in the interactions between client and service provider, which is offered as a solution to achieve desired end results for the client” in a SoHMS manufacturing operations can be represented by MServices that are executed over a product and can be realized by one or several resources in the system. MServices, as they represent validated operations, can be readily available to integrate different production processes, thus bringing the benefit of *reusability*. Moreover, resource capabilities are determined by the collection of MServices it offers. This facilitates the *integration of legacy systems* and different vendor technologies, as MService descriptions are determined according to their nature, in terms of added

transformations, with no regard of the methods that are used for their application. This allows a *complete separation of process specification from the knowledge on the production floor* making it implementable in any SoHMS platform providing the necessary MServices with the same application service ontology.

Service orientation is emerging at multiple organizational levels in enterprise business, and leverages technology in response to the growing need for greater business integration, flexibility and agility of manufacturing enterprises. Closely related to IT infrastructures of Web services, the service-oriented enterprise architecture represents a technical architecture, a business modelling concept, an integration source and a new way of viewing units of control within the enterprise. Business and process information systems integration and interoperability are feasible by *considering the customized product* as “*active controller*” of the enterprise resources—thus providing consistency between material and informational flows. The areas of service-oriented computing and multi-agent systems are getting closer, trying to deal with the same kind of environments formed by loose-coupled, flexible, persistent and distributed tasks. An example is the new approach of service-oriented multi-agent systems (SoMAS).

The unifying approach of the authors’ contributions for this Part V of the book relies on the methodology and practice of disaggregating siloed, tightly coupled business, MES and shop-floor processes into loosely coupled services and mapping them to IT services, sequencing, synchronizing and orchestrating their execution. Research is reported in: function block orchestration of services in distributed automation and performance evaluation of Web services; MAS with service-oriented agents for dynamic rescheduling work force tasks during operations; virtual commissioning-based development of a service-oriented holonic control for retrofit manufacturing systems; security solution for service-oriented manufacturing architectures that uses a public-key infrastructure to generate certificates and propagate trust at runtime.

**Part VI** is devoted to *Cloud and Computing-Oriented Manufacturing*, which represent major trends in modern manufacturing. Cloud manufacturing (CMfg) and MES virtualization were introduced as a networked and service-oriented manufacturing model, focusing on the new opportunities in networked manufacturing area, as enabled by the emergence of cloud computing platforms. The cloud-based service delivery model for the manufacturing industry includes product design, batch planning, product scheduling, real-time manufacturing control, testing, management and all other stages of a product’s life cycle.

CMfg derives not only from cloud computing, but also from related concepts and technologies such as the Internet of Things—IoT (core enabling technology for goods tracking and product-centric control), 3D modelling and printing (core enabling technology for digital manufacturing). In CMfg applications, various manufacturing resources and abilities can be intelligently sensed and connected into a wider Internet, and automatically managed and controlled using both (either) IoT and (or) cloud solutions. The key difference between cloud computing and CMfg is that resources involved in cloud computing are primarily computational (e.g. server, storage, network, software), while in CMfg all manufacturing resources and

abilities involved in the whole life cycle of manufacturing are aimed to be provided for the user in different service models.

Papers in this section present resource virtualization techniques and resource sharing in manufacturing environments. Resources and resource capabilities virtualization and modelling represent the starting point for manufacturing services encapsulation in the cloud. There is also shown that CMfg is clearly an applicable business model for 3D-printing—a novel direct digital manufacturing technology. In cyber-physical system (CPS) approach of manufacturing, a major challenge is to integrate the computational decisional components (i.e. cyber part) with the physical automation systems and devices (i.e. physical part) to create such network of smart cyber-physical components at MES and shop-floor levels. Some works present the development of standardized interfaces for HMES that can be used to access physical automation components by the cyber layer in CPS. A chapter of this section investigates the software-defined networking (SDN) concept adoption for the manufacturing product design and operational flow, by promoting the logical-only centralization of the shop-floor operations control within the manufacturing shared-cloud for clusters of manufacturing networks.

**Part VII** gathers contributions in the field of *Smart Grids and Wireless Sensor Networks* management and control with multi-agent implementing. Technological advances in wireless sensor networks are enabling new levels of distributed intelligence in several forms such as “active products” that interact with the working environment and smart metering for monitoring the history of products over their entire life cycle and the status and performances of resources. These distributed intelligences offer new opportunities for reducing myopic decision-making in manufacturing control systems, thereby potentially enhancing their sustainability.

Design of such MAS frameworks for distributed intelligent control and development of applications integrating intelligent-embedded devices are reported in Part VII for several representative domains. Thus, a solution for space system management is proposed by creating a self-organizing team of intelligent agents, associated to spacecraft modules, conducting negotiations and capable of both planning their behaviour individually in real time and working in groups in order to ensure coordinated decisions. Then, an embedded multi-agent system for managing sink nodes and clusters of wireless sensor networks is proposed and finally demonstrated in an oil and gas refinery application. To reduce the communication overhead in the MAS, the wireless sensor network is clustered which leads to a hierarchical structure for the WSN composed of two types of sensor nodes: sink nodes (cluster heads) and anchor nodes (sending sensory data to the sink nodes) allowing for data aggregation. Finally, this section describes a methodology and framework for the development of new control architectures based on uncertainty management and self-reconfigurability of smart power grids.

The book offers a new integrated vision on *complexity*, *Big Data* and *virtualization in Computing-Oriented Manufacturing*, combining emergent information and communication technologies, control with distributed intelligence and MAS implementation and total enterprise integration solutions running in truly distributed and ubiquitous environments. The IMS philosophy adopts heterarchical and



collaborative control as its information system architecture. The behaviour of the entire manufacturing system therefore becomes collaborative, determined by many interacting subsystems that may have their own independent interests, values and modes of operation. Also, the enrichment of distributed systems with biology-inspired mechanisms supports dynamic structure reconfiguration, thus handling more effectively condition changes and unexpected disturbances, and minimizing their effects.

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

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