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# Service Orientation in Holonic and Multi Agent Manufacturing and Robotics

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# Preface

This book gathers the most representative papers presented at the second edition of the International Workshop "Service Orientation in Holonic and Multi-agent Manufacturing and Robotics – SOHOMA'12" organized on May 23–24, 2012 as special tracks F and G of the 14$^{th}$ edition of the IFAC Symposium on "Information Control Problems in Manufacturing – INCOM'12".

SOHOMA scientific events are organized in the framework of the European project no. 264207 ERRIC, the objective of which is to foster innovation in manufacturing control through intelligent IT and in this context to empower excellence in research at the faculty of Automatic Control and Computer Science within the University Politehnica of Bucharest.

The book is structured in four parts, each one covering a specific research domain which represents a trend for modern manufacturing control: Holonic and Multi-agent technologies for industrial systems (Part I), Intelligent Product and Product-driven Automation (Part II), Service Orientation of Enterprise's strategic and technical processes (Part III), and Distributed Intelligent Automation Systems (Part IV).

These four evolution lines have in common concepts related to *service orientation*; today it is generally recognized that the Service Oriented Architecture paradigm has been looked upon as a suitable and effective approach for industrial automation and manufacturing management and control.

Engineering complex enterprise (manufacturing or service) systems is the process of engineering of manufacturing and service large-scale systems such as distributed manufacturing operations and globally distributed supply and demand chains (value chains), which involve a large number of interacting entities, and have several stakeholders with different objectives.

Since traditional systems engineering and its methods and tools coming from operations research, computer science, and decision sciences cannot address the increased complexity of today's engineered and organizational systems, engineering should borrow from complex systems research which offers the possibility to build a framework using already studied concepts such as complexity, big data analytics, fractals, emergence, self-organization, adaptation, evolution, etc.

Several frameworks are proposed for classifying, analysing initiatives and potentially developing distributed intelligent automation systems. These frameworks will be referred to in the book as the *Distributed Intelligent Automation Systems Grid*. In particular we are interested in systems in which the planning or execution of tasks normally associated with a particular operational level are reassigned to be carried out instead by a number of units at a different level. Or conversely, a task normally using information from a single source makes use of data spread across a range of operations – and potentially a range of organisations.

The book defines and explains the main ways to implement intelligent products: by putting intelligence at the object (Intelligent Embedded Systems) or through the computing network (using Automatic Identification and Data Capture technology attached to the product to allow it to be identified by a computer system). These technologies enable the automated identification of objects, the collection of data about them, and the storage of that data directly into computer systems. Through this network, the computer system can a) access or write information in databases about the product and b) link with a software agent which is responsible for the communication and decision-making features.

The service-oriented multi-agent systems (SoMAS) approach discussed in the book is characterized by the use of a set of distributed autonomous and cooperative agents (embedded in smart control components) that use the SOA principles, i.e. oriented by the offer and request of services, in order to fulfil industrial and production systems goals. This approach is different from the traditional Multi-agent Systems (MAS) mainly because agents are service-oriented, i.e. individual goals of agents may be complemented by services provided by other agents, and the internal functionalities of agents can be offered as services to others agents (note that these service-oriented agents do not only share services as their major form of communication, but also complement their own goals with different types of external provided services).

Special attention is paid in the book to the framework for manufacturing integration, which matches plant floor solutions with business systems and suppliers. This solution focuses on achieving flexibility by enabling a low coupling design of the entire enterprise system through leveraging of Service Oriented Architecture (SOA) and Manufacturing Service Bus (MSB) as best practices.

The *Manufacturing Service Bus* (MSB) integration model introduced in Part I of the book is an adaptation of ESB for manufacturing enterprises and introduces the concept of bus communication for the manufacturing systems. The MSB acts as an intermediary (middle-man) for the data flows, assuring loose coupling between modules at shop floor level.

The book offers a new integrated vision combining complementary emergent technologies which allow reaching control structures with distributed intelligence supporting the enterprise integration (vertical and horizontal dimensions) and running in truly distributed and ubiquitous environments. Additionally, the enrichment of these distributed systems with mechanisms inspired by biology supports the dynamic structure reconfiguration, thus handling more effectively with condition changes and unexpected disturbances, and minimizing their effects. As an example, the integration of service-oriented principles with MAS allows to combine the best of the two worlds, and in this way to overcome some limitations associated to multi-agent systems, such as interoperability.

A brief description of the book chapters follows.

**Part I** is devoted to *Holonic and Multi-agent technologies for agile manufacturing*. The demand for large-scale systems running in complex and even chaotic environments requires the consideration of new paradigms and technologies that provide flexibility, robustness, agility and responsiveness. Holonic systems are, actually by definition, targeting challenges that include coping with the heterogeneous nature of industrial systems and their on-line interactive nature in combination with competitive pressures. Multi-agents systems is considered as a suitable approach to address these challenge by offering an alternative way to design control systems, based on the decentralization of control functions over distributed autonomous and cooperative entities. This part of the book gathers contributions on on-line simulation and on benchmarks aiming at delivering open systems which feature interoperability, optimization in decentralized structures and real self-adaptation - with emphasis on manufacturing systems for which agility is considered.

**Chapter 1** presents developments on a collaborative framework between a centralized manufacturing scheduling system (SS) and a decentralized manufacturing execution system (dMES); the integration of these systems aims at reducing the existing gap between detailed manufacturing scheduling systems and lower level systems, like MESs. The framework exploits the benefits of each specialized technology and complements their capabilities in order to collaborate at runtime. The SS is based on constraint programming (CP) technology, while the holonic MES or HMES implements the PROSA reference architecture and applies the delegate multi-agent system pattern (D-MAS). The chapter also shows the impact that disruptive events have on the execution performance. Experimental results show a trade-off between efficiency and stability metrics.

**Chapter 2** describes a framework for manufacturing integration, which matches plant floor solutions with business systems and suppliers. This solution focuses on achieving flexibility by enabling a low coupling design of the entire enterprise system through leveraging of Service Oriented Architecture (SOA) and Manufacturing Service Bus (MSB) as best practices. The paper presents the integration between an upper layer ESB-based business system with a distributed HMES system based on MSB, built using JADE multi agent platform, event-triggered communication and dynamic business rules. The combination of ESB at business layer and MSB at HMES layer forms a solid yet agile architecture for loose coupled, standard based manufacturing systems. Experimental results show the distribution of messages transmitted through the ESB and MSB for a certain product batch size and number of resources, proving that two-layered bus architectures offer several advantages in structuring the information flow through the buses.

**Chapter 3** discusses a new perspective to engineer adaptive complex systems considering a 3-layer framework integrating several complementary paradigms and technologies. In a first step, it suggests the integration of multi-agent systems with service-oriented architectures to overcome the limitations of interoperability and smooth migration, followed by the use of technology enablers, such as cloud computing and wireless sensor networks, to provide a ubiquitous and reconfigurable environment. Finally, the resulted service-oriented multi-agent system should be enhanced with biologically inspired techniques, namely self-organization, to reach a truly robust, agile and adaptive system.

**Chapter 4** analyses the BDI reasoning mechanism as AI inference approach and its use in solving the deliberative phase of holonic agents within Holonic Manufacturing Execution Systems. The chapter presents the main issues on applying the BDI mechanism in a new holonic structure named HAPBA, which is an instantiation of PROSA reference architecture. The appropriate Petri net models are presented, allowing the analysis of the holonic scheme performance.

**Chapter 5** discusses methods and techniques for after-sales delivery process modelling and measurement, in the context that complementing industrial goods with the provision of value added services can be an important lever to prosper on those markets affected by weak demand, hard competition and decreasing margins. It is shown that the increasing role of industrial services in the strategic plans and the economics of companies pose new relevant organisational and management challenges;

**Chapter 6** analyses the similarities between different categories of manufacturing systems: bionic-, holonic- and fractal-, having in common the property of self-organization and a multi-agent architecture. As a novelty, the paper proposes a methodology to aid engineers in the design and control of Fractal Multi-Agent Systems for manufacturing applications. This methodology offers a conceptual framework and a series of steps to follow to find proper mechanisms that will promote elements which, by actively interacting among them, lead to better performance.

**Part II** gathers contributions analysing the concept of *Intelligent Product* and related techniques for *Product-driven Automation*. The rapid development of this concept is mainly due to the fact that, over the last decade, the increasing growth of embedded technologies (e.g., RFID, smart cards, wireless communication), associated with the concepts of ambient intelligence and machine-to-machine intelligence, has allowed the development of products that are fully able to interact in an intelligent mode with their environment. Also, working on the closed-loop PLM (Product Life Cycle Management), interoperability and traceability topics leads to some relevant specifications that can be applied using an "intelligent product" approach, from the product's design to its recycling. Closed-loop PLM focuses on the complete product life cycle, with an emphasis on tracking and managing the information from the whole product life cycle and potentially returning information to each phase in the creation and delivery stages.

**Chapter 7** makes an analysis ten years after the intelligent product model was introduced as a means of motivating a supply chain in which product 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 was enabled by the evolution of low cost RFID systems which promised low cost connection between physical goods and networked information environments. In 2002 the notion of product intelligence was regarded as a useful but rather esoteric construct. However, in the intervening ten years there have been a number of technological advances coupled with an increasingly challenged business environment which make the prospects for intelligent product deployment seem more likely. This chapter reviews a number of these developments and assesses their impact on the intelligent product approach.

**Chapter 8** evaluates one of the main standards proposed for inter-organizational data exchange for track and trace purposes in the supply chain - GS1's Electronic Product Code Information Services (EPCIS). The chapter analyses why EPCIS has not been universally adopted as a global data-exchange standard for track and trace by discussing three application areas where the use of EPCIS should provide substantial benefits. The results of this analysis should provide useful insights into the challenges of introducing new, global standards and guidelines for similar future initiatives.

**Chapter 9** presents the concept of Product-Driven Control (PDC) more precisely, the stakes (i.e., the expected advantages and the problems to be solved), and the relevant research. Several industrial examples are provided to illustrate the concept. Finally, some challenging prospects are proposed to give an overview of the potential benefits of this approach in the near future.

**Chapter 10** provides insights into the foundations of the Physical Internet that has been introduced as a solution to the Global Logistics Sustainability Grand Challenge. The Challenge sets as its goal to improve, by an order of magnitude, the economic, environmental and social efficiency and sustainability of the way physical objects are realized, moved, stored, supplied and used across the world. The paper introduces a formal definition of the Physical Internet as an open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols. It is a perpetually evolving system driven by technological, infrastructural and business innovation. In line with the proposed definition, this chapter explains and provides insights into eight foundations of the Physical Internet: a means for logistics efficiency and sustainability, universal interconnectivity, encapsulation, standard smart interfaces, standard coordination protocols, logistics web enabler, an open global logistics system, and driven by innovation.

**Chapter 11** describes the evolution of flexible manufacturing systems from a data-oriented perspective to a product-driven one. The two directions in which production control of industrial systems evolved for the past decade, contradictory at a first glance, are analysed. The first evolution results from a deeper integration of all actors in industry - from raw materials suppliers to customer service department dealing with customers' rising demands. This is known as the concept of "global supply chain" in a globalized market. The second evolution is due to an increasing need for flexibility and reactivity, on one hand to answer to an increasing variety in product demand, and on the other hand to react better to disruptions occurring in manufacturing systems of increasing complexity. These evolutions imply a deep modification of the manufacturing system's structure, progressively evolving from a hierarchical organization (where decisions are taken from one level to the next one, from top to bottom) to a networked organization (where each node of the network is to some extent more or less an autonomous decision centre). This control concept is described in the chapter, because through modelling of uncertainties and disruptions it ensures a significant increase of the global production system robustness.

**Chapter 12** introduces an approach to data mining for product-driven systems. Several options are proposed that allow materials and products to react to environmental modifications, especially in manufacturing and logistics contexts. At present, bio-inspired approaches are particularly promising, because they allow products to respond to the information they collect and process according to efficient data analytics methods. The chapter highlights the way learning machines are perceived as a new means of transforming data into useful knowledge.

**Part III** approaches the trend of *service orientation in the management and control of manufacturing processes*. The 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. Close related to IT infrastructures of Web Services, the Service Oriented

Architecture represents a technical architecture, a business modelling concept, an integration source and a new way of viewing units of automation within the enterprise. Business and process information systems integration and interoperability 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 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 that reinforce the value of commoditization, reuse, semantics and information, and create business value. The unifying approach of the contributions for this third part of the book relies on the methodology and practice of disaggregating siloed, tightly coupled business processes at manufacturing enterprise level into loosely coupled services and mapping them to IT services, sequencing, synchronizing and automating the execution of processes which encapsulate the software description of such complex business processes related to agile production by means of distributed information systems.

**Chapter 13** describes the efforts that are undergoing within engineering systems community to account for the increased complexity of today's manufacturing or service systems. These systems are becoming more and more complicated due to the increase in the number of elements, interconnections within the system, and necessary integration with other systems. Moreover, through the emphasis on self-organization and considering the multi-stakeholders context and objectives, such systems are crossing the line towards complexity. The chapter points out the need for developing a framework to be used in modelling, analysing, and integrating systems that operate in uncertain environments in which characteristics such as adaptation, self-organization and evolution (in other words behaviour prediction) need to be addressed. The proposed complex enterprise systems framework combines knowledge coming from complex systems science and systems engineering domains, and uses computational intelligence and agent-based systems simulation methodologies; this approach requires computational experience in manipulating large amounts of data and building large-scale simulation models.

**Chapter 14** proposes an integrated approach that stretches from the process planning phase, through the implementation phase and all the way to the phase for execution of the process control logics. This approach uses the concepts of service-oriented architectures within automation technology, here referred to as SOA-AT. As service technology, Devices Profile for Web Services (DPWS) has proved to be the most suitable for realizing service based communication on device level. The chapter shows how Grafchart, a graphical language aimed for sequential control applications, can support the development of DPWS applications, and how Grafchart can be used for process modelling and execution in the planning and execution phase. This constitutes a unique framework for the development and execution of SOA applications in accordance with the requirements for automatic control tasks; the chapter also presents an industry-related experimental setup in which the SOA-AT concepts are demonstrated through the use of Grafchart.

**Chapter 15** presents the prototype of a knowledge sharing environment dedicated to Service Science development and dissemination in the manufacturing context. The proposed concept model of the Service Science Knowledge Environment is developed on three directions, i.e. research, education and business alliances. The chapter emphasizes the way in which value co-creation can profit from semantic-driven social software, taking into consideration the case of educational services delivered in the cloud. As current ICT state-of-the-art allows creating new services connected to the traditional manufacturing and business domains, the chapter gives a perspective on manufacturing servitization processes.

**Chapter 16** aims at bridging the gap in a semi-automated way between the design-time description and the runtime integration of industrial automation systems. The chapter focuses also on the problem of integrating legacy systems with limited access to original engineering data. It is assumed that an interface between a real industrial system and software automation tools is OPC Unified Architecture (OPC UA) from the tag list of which the plant knowledge is derived. The tag list adopts the naming convention defined by the international standard IEC 81346 which is widespread in large-scale systems, in order to solve this task in general. Consequently, the plant knowledge is mapped to knowledge related to software automation tools, such as simulations.

**Chapter 17** examines a flexible communication architecture approach for vertical integration of production process-relevant data, i.e., for closing the gap between the business (strategic) and technical (operations) levels. Today's global competition and rising prizes for resources force manufacturing companies to integrate and make use of various IT systems in their production environment. These IT systems need to be directly connected with the manufacturing plants to optimize the value added chain in all levels of the enterprise. The approach enables the transfer of information in form of key performance indicators which will support decision-making processes in the manufacturing companies. To prove the feasibility of the vertical integration approach a prototype is implemented and evaluated in the *SmartFactory*$^{\mathbf{KL}}$**.**

**Chapter 18** proposes a new control method for the movement of wheeled mobile robots performing manufacturing supply services in the presence of static and dynamic obstacles. The dynamic model used for steering and obstacle avoidance is the differential equations system. The environment is perceived by the commonly used laser range finder system, whereas the obstacle avoidance problem is solved using the trajectory tracking control. The sliding mode control approach is used for the trajectory tracking problem. The effectiveness of the proposed local navigational system in an unknown environment with static and moving objects, corresponding to flexible manufacturing system, is proved through simulation results.

**Part IV** reports recent advances and on-going research in *sustainable manufacturing based on distributed approaches* such as Multi-Agent Systems and Holonic Manufacturing Execution Systems. Distributed intelligences offer new opportunities for developing techniques to reduce myopic decision making in manufacturing control systems thereby potentially enhancing their sustainability. This last part of the book gathers a number of chapters describing services for architecting highly distributed intelligent operation of manufacturing enterprises, consisting of production processes, lighting and HVAC systems, renewable energy systems, and energy storage systems to cooperatively achieve load control, and implicitly thereby real-time emission management. Such distributed, intelligent systems will leverage emerging developments in service oriented architectures and in interoperability standards for the smart grid. The section extends recent developments in intelligent product-driven production for combining distributed production scheduling and power consumption scheduling.

**Chapter 19** presents a simulation model that integrates the machine-level energy control policies with production control policies in order to develop a holistic approach characterizing energy dynamics in discrete manufacturing systems. It is shown that in discrete manufacturing systems consisting of multiple machines, energy consumption of individual machines can be expected to be influenced by the higher-level production control systems and its associated policies. Results from an exploratory study indicate that production control policies can significantly influence the amount of energy wasted in manufacturing systems.

**Chapter 20** proposes a simple and pragmatic framework that has been developed for classifying and analysing developments in distributed automation and information systems – especially those that have been labelled *intelligent systems* for different reasons. The framework dissects the different stages in the standard feedback process and assesses distribution in terms of the level of granularity of the organization that is being considered. The framework has been found to be useful in comparing and assessing different distributed industrial control paradigms and also for examining common features of different development projects – especially those that might be sourced from different sectors or domains.

**Chapter 21** gives an overview of alternative control approaches that have been applied in industrial automation domain for more than two decades. Apart from more traditional centralized and hierarchical approaches, the discussed ones are built on distributed, autonomous and intelligent entities that provide and consume services in networked environments. The key drivers have been holonic concept, multi-agent systems and recently service-oriented architectures. The chapter discusses the major benefits as well as prevailing roadblocks hindering the widespread exploitation and deployment in real factories. It reviews the principle methodologies, architectures, tools and either pilot trials or commercially successful applications of industrial agent systems with major focus on achievements of the Rockwell Automation company.

**Chapter 22** introduces a new optimization problem that aims at minimizing the reconfiguration cost of a transfer line. A line has to be reconfigured if a new product must be produced by an existing line or any changes in product characteristics occur. In such cases, new operations have to be integrated on existing equipment while some previously assigned operations are deleted. Since transfer lines consist of a sequence of unit head machines, their reconfiguration is not an easy issue because of numerous constraints on compatibility between old and new operations to be taken into account. Therefore, a compromise between introducing new equipment and reusing old one is proposed. In this chapter, a Mixed Integer Program is proposed for solving this problem with objective to minimize the cost of the final line configuration.

**Chapter 23** identifies the main challenges addressed by knowledge-based production systems and investigates the state of the art in supporting factory engineering and control with knowledge-based technologies. The paper concludes with a discussion of white spots in the research landscape. While there is comprehensive research on applying knowledge-based technology to individual problems such as disruption detection or reactive production planning, the interaction and dependencies between those solutions is less well investigated – although a combined solution is inevitable for addressing real world challenges.

**Chapter 24** discusses a new method of tracking and controlling robots that interact with humans (natural interaction) to provide assistance services in manufacturing tasks. Natural interaction is implemented using a depth sensor which monitors the human's activity outside and inside the robot system workspace to prevent collisions and accidents. The sensor extracts depth data from the environment and uses the processing power of a workstation in order to detect both humans and robot arms. This is done by detecting skeletons which represent the position and posture of the humans and manipulators. Using skeleton tracking, a software agent monitors the movements of the human operator and the robotic arm to detect possible collisions and to stop the robot motion in right time. Also the agent can interpret the posture (or full body gesture) of the human operator in order to send basic commands to the robot for dexterous task emulation.

The *service value creation model* at enterprise level consists into using a **Service Component Architecture** (SCA) for business process applications, based on entities which handle (provide, ask for, monitor) services. In this componentization view, a service is a piece of software encapsulating the business / control logic or resource functionality of an entity that exhibits an individual competence and responds to a specific request to fulfil a local (product operation, verification) or global objective (batch production).

If SOA is the conceptual framework for service orientation of manufacturing enterprise processes, **Service Oriented Computing** (SOC) represents the methodology and implementing framework for embedded monitoring and control systems in *Service Oriented Enterprise Architectures* (SOEA).

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

October 2012

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