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An engineering framework for Service-Oriented Intelligent Manufacturing Systems

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ABSTRACT

Nowadays fully integrated enterprises are being replaced by business networks in which each participant provides others with specialized services. As a result, the Service Oriented Manufacturing Systems emerges. These systems are complex and hard to engineer. The main source of complexity is the number of different technologies, standards, functions, protocols, and execution environments that must be integrated in order to realize them. This paper proposes a framework and associated engineering approach for assisting the system developers of Service Oriented Manufacturing Systems. The approach combines multi-agent system with Service Oriented Architectures for the development of intelligent automation control and execution of manufacturing systems.

1. Introduction

The rapidly changing needs and opportunities of todays global market require unprecedented levels of interoperability to integrate diverse information systems to share knowledge and collaborate among organizations. Fully integrated enterprises are being replaced by business networks in which each participant provides others with specialized services [1]. Almost no enterprise is able to accomplish all the production processes to offer a product or a product service system (PSS) independently. As a result, the Service Oriented Manufacturing Systems (SoMS) emerges.

A promising approach to develop SoMS is the integration of multi-agent system (MAS) and/or Holonic Manufacturing Systems (HMS)[1] with Service Oriented Architectures (SoA). MAS represents one of the most promising technological paradigms for the development of open, distributed, cooperative, and intelligent software systems. It has already been successfully applied to the field of Intelligent Manufacturing Systems (IMS) [4]. Moreover, the areas of SoA and MAS are getting closer and closer. In fact, in spite of both trying to deal with the same kind of environments formed by loose-coupled, flexible, persistent and distributed tasks [5], MAS and SoA present some important differences, namely in terms of autonomy and interoperability (see [6] for an in-depth study). Some researches state that the lacks in terms of interoperability exhibited by the MAS solutions in the manufacturing field can be overcome by combining SoA principles, and especially by using Web services technology [7]. An example of this fact is the new approach of Service Oriented Multi-agent Systems (SoMAS).

One of the critical aspects when developing SoMS is the complexity of the development process and the system itself. The system engineer needs support from software engineering methods and frameworks in order to manage the complexity originated by the number of different technologies, standards, functions, protocols, and execution environments that must be integrated in order to realize the SoMS. To the best of the authors' knowledge there is no complete engineering method in the specialized literature that can assist the system engineer during the whole life-cycle (requirements' specification, analysis, design, implementation, validation and verification, deployment, maintenance and operation) of a SoMS. Moreover, todays' changing

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[1] HMS is a paradigm that translates the concepts of living organisms and social organizations developed by Koestler [2] to the manufacturing world. A holon is an identifiable part of a system that has a unique identity, yet is made up of subordinate parts and is in turn part of a larger whole. The holons can represent physical resources and logic entities, with intelligent and cooperative capabilities. In this paper we use agents and/or holons in order to refer to the intelligent software components that made up an Intelligent Manufacturing System. For a detailed comparison of the two concepts see [3].

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market requirements force these systems to have some agility, reconfigurability and flexibility features in order to respond in a satisfactory and competitive way. The authors believe that MAS approaches can help to achieve all these features, and propose a service oriented engineering framework specifically tailored to deal with the development of IMS based on services and oriented to services. In this work it is presented a MAS based infrastructure for assisting the system developers when developing Service Oriented Intelligent Manufacturing Systems (SoIMS).

The proposed approach is called ANEMONA-S + Thomas framework. The initial ideas of the framework were presented in [8], whereas in current paper an in-depth analysis of the details of the framework is presented, augmented with new guidelines and steps that complete the framework. The background on SoMS is presented in Section 2, together with a discussion on related works. The proposed framework is described in Section 3. In Section 4 the usefulness and completeness of the approach is evaluated. The conclusions and future works are analyzed in Section 5.

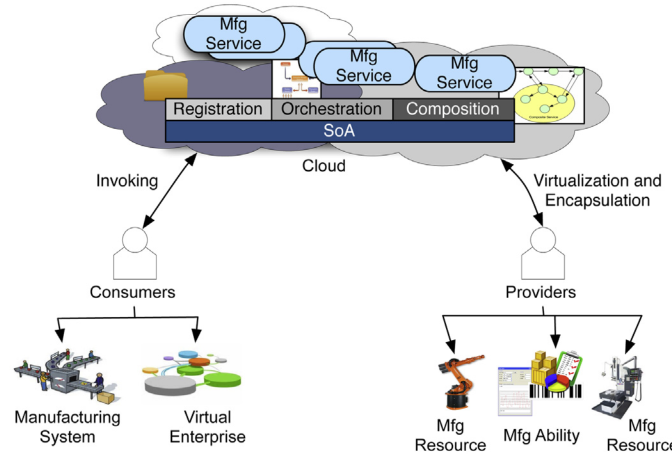

Fig. 1. Cloud manufacturing abstract execution.

2. Cloud manufacturing and service oriented manufacturing

Cloud manufacturing is a computing and SoMS model developed from existing advanced manufacturing models and enterprise information technologies. Cloud computing, Internet of Things, virtualization and service-oriented technologies, and advanced computing technologies are the information technologies that support the realization of cloud manufacturing.

In a cloud manufacturing system, various manufacturing resources and abilities can be intelligently sensed and connected into the wider Internet by means of SoA principles, see Fig. 1. In this way the manufacturing resources and abilities, from *Providers*, are virtualized and encapsulated into different manufacturing cloud services (*Mfg Services*) that can be accessed, invoked, deployed, and on-demand used by *Consumers*. An example of such approach is that SCADA and MES functions start being provided as services partially located in service clouds [9].

Service-based manufacturing network (or collaborative manufacturing virtual enterprises) is the manufacturing paradigm for the production of products and PSS.[2] In service-based manufacturing network, each enterprise focuses on core businesses, outsources non-core businesses (buy *Mfg Services*), and provides producer services (sell *Mfg Services*) for one another to achieve rapid innovation and improve efficiency. In this way, the integration of service and manufacturing has also changed the product pattern and not only the manufacturing paradigm [11]. The physical product is servitized or integrated with services to form PSS.

The complexity of SoMS is high due to large number of different elements and the need to integrate different components, standards, functions, protocols, and execution environments into a single system. Moreover, the development process of such system needs to be guided and supported by appropriate and complete software engineering methods that can help the developers to manage the complexity. Key fundamental features in the development process of SoMS are: (i) specific notation and method support for the identification and specification of the system components that will implement the *Providers* and *Consumers* in the SoMS; (ii) specific and complete guidelines to specify and implement the *Mfg Services* that will made up the SoMS; (iii) design and implementation artifacts that facilitate the development of agile, flexible and reconfigurable SoMS; (iv) an execution platform for supporting the deployment of SoMS in which open and dynamic system execution (run-time creation, modification and deletion of *Mfg Services*, *Providers* and *Consumers*) are allowed; (v) a uniform approach for design and implementation that facilitate the interconnection among components and levels in the SoMS (encouraging the use of standards). These key issues motivated the authors to propose ANEMONA-S + Thomas approach for the development of SoMS.

In the specialized literature we can find some works in the field of SoMS. Adacor II [28] is an engineering framework based on distributed control systems and service oriented design paradigms. A Petri net-based language is used for intra and inter-coordination activities. Nevertheless, the proposed approach is very interesting and complete in terms of the set of tools that can be used, the approach lacks engineering guidelines. Moreover, there is a lack of uniform specification language and modeling concepts. In [29] an agent-based approach is described for modeling PSS. Nevertheless, the approach is limited only to the modeling of the life-cycle of the PSS after sell, i.e. in execution or in use. On the other hand [1] uses agent-based service-oriented approaches for the business level of virtual enterprise cooperation. In it the companies share resources by means of an agent-based infrastructure built on top of service-oriented technologies in order to define virtual enterprises. The SoMAS approach defined in ANEMONA-S is close to the work presented in [7]. Nevertheless, in [7] there is lack of methodological process to assist the system developer during system development. The ANEMONA-S method can be used to complement it in order to help the system designer at every development step. PROSIS [30] is a service oriented architecture based on PROSA type of holons as well as ANEMONA-S. PROSIS provides a set of specialized services that can be parameterized in order to use them in product, resource and order holons. Nevertheless, in PROSIS there is no methodological support for the development process. The SoA and MAS architecture described in [33] implements a set of layers and pre-defined platform supplied services that can be used for manufacturing automation level 2 of an ISA95/IEC 62264 standard architecture [31]. This proposal can be combined with the ANEMONA-S development process in order to populate the Service Cloud with application dependent services for specific manufacturing systems. The Thomas platform can be used also to implement the Service Cloud and the specialized services. IMC-AESOP [34] and SOCRADES [35] are two complete frameworks for implementing Cyber-Physical Systems using SoA. Nevertheless, both lack methodological support. ANEMONA-S development process can complement these two frameworks providing the support of engineering methods and notation.

[2] A PSS is an integrated system in which the traditional functionality of a product is expanded by additional services. PSS shifts the focus to the usage of the product, that is, the customer does not pay for the possession of a product, but for the use of the product or for the functionality he receives [10].