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A modeling framework for manufacturing services in Service-oriented Holonic Manufacturing Systems

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ABSTRACT

Holonic and Service-Oriented Architectures have been proposed as solutions for the conception of flexible and reactive systems. The combination of both architectures has been recognized as an attractive solution for the conception of more flexible and reactive systems. Services, originally conceived for web applications, need new models that better adapt to the needs of manufacturing systems namely, the specification and planning of processes. This paper proposes a methodology for designing customizable product-process specifications based on manufacturing-services that are suitable for product driven applications. A framework is proposed for modeling manufacturing-services designed for its application in Holonic Manufacturing Systems, preserving the fractal character found in products and processes. Three types of manufacturing processes are identified based on the relations among its composing operations and a model is proposed for each type. Application service-ontologies are created to describe operations and resource capabilities rather than complex semantic descriptions to facilitate process design and reduce the computational load of service discovery for planning. The framework leverages service reusability among process families in the same way as physical features are reused among product families. An illustrative example describes the design of a product's process specification based on the manufacturing service framework in a Holonic Manufacturing System, giving rise to Service-oriented Holonic Manufacturing Systems.

1. Introduction

An evolution in the goods market has been witnessed for the last few decades with a trend towards highly customized products and shorter product lifecycles. Such trend, expected to rise in the near future, is forcing companies on 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. The conception of "Next Generation Manufacturing Execution Systems" (NGMES), with the aforementioned attributes, has been challenging the community of Intelligent Manufacturing Systems, in a research guided by industry with the aspiration to incorporate "Agile Business" in manufacturing systems. Holonic Manufacturing Systems (HMS) and Service-Oriented Architectures (SOA) have been two of the most studied and referenced solutions, the former in manufacturing applications while the latter in informatics but making its way into industrial applications (such as in (Borangiu et al., 2012b)). Both of these solutions provide the necessary guidelines to create open, flexible and agile control environments for the NGMES.

The Holonic paradigm has been recognized, in industry and academics, as a provider of above mentioned attributes by means of a decentralized control architecture formed by a social organization of intelligent entities, called Holons, with specific behaviors and goals (Dehimi et al., 2015), defined by a reference architecture such as in (Chirn and McFarlane, 2000; Leitão and Restivo, 2006; Van Brussel et al., 1998). In another domain (computer science), the service-oriented paradigm defines the principles for conceiving decentralized control architectures that decompose computational processes into sub-processes, called *services*, to later distribute them among the different resources available (Rodríguez et al., 2016). Its focus is to leverage the creation of reusable and interoperable function blocks in order to reduce the amount of reprogramming efforts.

The combination of both paradigms appears to be a very attractive solution to the NGMES challenge as seen in works such as (Bellifemine et al., 2007; Jammes et al., 2005; Jammes and Smit, 2005) or more recently (Morariu et al., 2013a).This, thanks to the flexibility

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provided at a structural level of the control architecture and at a process level with the distribution and encapsulation of processes, was implemented using HMS and SOA respectively. Many recent works in literature have highlighted its benefits and proposed the use of services for the conception of control architectures and strategies for complex systems, such as the SOHOMA community (Borangiu et al., 2012b). However, until now, there has not been found works proposing a formal description of the informational elements forming and describing a service nor how this can form process specifications when integrated in the context of the manufacturing domain. Services, originally conceived for web applications, need new and more adequate models for their application in manufacturing systems. As services are the main element of negotiation in a service-oriented context, it is essential to define an appropriate model on which new architectures and interactions can be build up properly.

The design a Flexible Control System is a task that necessitates three successive steps: (i) the definition of an *Information Model*, (ii) the structural definition of the *Control Architecture* (defining the role of each entity in the architecture) and (iii) the definition of the *Negotiation Mechanisms* and/or *Optimization Methods/Strategies* enhancing the performance of the system. To obtain a truly agile control system, all these steps need to foster flexibility and reconfigurability. The objective of this work deals with the first of these issues: propose an information model based on the design principals of SoA adapted to the manufacturing context in order to respond to the interest of this domain such as interoperability, reusability and reconfigurability. Moreover, this adaptation is intended for its insertion in the classical Holonic Control Architectures such as PROSA (Van Brussel et al., 1998) that will provide process flexibility to the design of optimization strategies. The way these optimization tasks are defined and implemented is considered out of scope of this work. This work is motivated under the belief that the system's flexibility, being our main attribute of interest, is greatly determined by the way information is presented to the system, particularly at process specification. The objective of this paper is to propose a framework for designing Manufacturing Services (MServices) to form processes specifications that will allow the HMS's control architecture to explore the added process flexibility provided by the decomposition and encapsulation of process operations, now identified as MServices. These MServices represent an extension of the commonly known Processing Services, as those are related to some operations for processing or transforming the product in a manner determined by user-specific parameters (Sahin and Gumusay, 2008).

The paper is organized as follows. Section 2 reviews the existing process and service specifications from which terms and ideas are extracted. Section 3 presents the modeling framework describing what MServices are, and introduces the models of the MService perspectives. Section 3.2 revises the MService parameter model and how services are parametrized. Finally the methodology for process specification using the MService framework is described through an illustrative example in Section 4.

2. Existing service specifications in manufacturing

Many works suggest the integration of Web Service technology in industrial systems: (Komoda, 2006) points out the issues for its application; (Mendes et al., 2010, 2009) propose Petri-Net controllers for processes formed by services; (Nagorny et al., 2012) propose a service-oriented manufacturing architecture with multi-agent technology; among others. Nevertheless, there has not been found works with a detailed description of what a service represents in the manufacturing context and what are its composing elements in order to build fractal processes and ensure their integral description.

Regarding the integration of service in the manufacturing domain many works have considered their integration in industrial applications. For instance (Komoda, 2006) in its work points out the issues and benefits of such integration, (Mendes et al., 2010, 2009) proposes the creation of Petri-Net controllers for processes formed by services as well as a template for modeling the execution of such services.; (Nagorny et al., 2012) propose a service-oriented manufacturing architecture with multi-agent technology. In the same matter, (Borangiu et al., 2012a) identifies various types of services, namely: Space transformation services, time transformation services and form transformation services, in a control structure classified according to the active character of their entities. Other works use the concept of service with a different perspective such as in (Dubromelle et al., 2012) where services are used to model activities internal to the control system and not to describe transformation operations but as ad-hoc services namely: hosting services, decision support service, state machine sync service, among other.

Even if many works recognize the benefits of integrating SoA's principles in the conception of new control systems and of new operation protocols, none has been found to describe, in detail, what a service represents in the manufacturing context, nor how these can be composed. In order to create coherent service oriented architectures and protocols, there is a need to define what are the information elements composing a service (capable of describing its capabilities and limits) as well as how these can be integrated in the decision making processes. Moreover, there is a need to define a framework for creating manufacturing services for new applications as well as how to form processes by defining relations between the composing services in a manufacturing context.

In the domain of computer science, the *Web Service* technology constitutes the preferred implementation vehicle by developers and platforms for Service-Oriented Architectures. Within this technology, there exists a series of core standards for the application of SoA's principles, such as the *Web Services Description Language (WSDL)* (a XML-based language dedicated to the abstract description of a service interface for its proper invocation) or the *Business Process Execution Language (WS-BPEL)* (also an XML-based language developed to describe the different workflows that can be composed by the collection of Web services). More advanced research on service specification is that on the *Semantic Web Service* technology. This technology proposes a new paradigm, intended to define how intelligent components represent and process knowledge about themselves, about other inner components and about the environment. The main idea is to provide machine-interpretable semantics so that devices can gain knowledge about other devices through machine-based reasoning and inference instead of a direct match-making of skill sets. The *OWL-S*, developed by W3C, is a Semantic Web ontology language providing the standard vocabulary that can be used to create computer-interpretable descriptions in order to access services.

However, these ontologies and description languages have been designed for web applications, which have similar but different interests to those found in manufacturing applications. For instance, web applications are mainly focused on interoperability and service discovery, while in manufacturing, the exploration of process flexibility comes more into play during the stage of process planning. Works such as (Delamer and Lastra, 2006; Jammes and Smit, 2005; Lastra and Delamer, 2006) have foreseen the application of semantic web services using OWL-S in factory automation. However, apart from interesting and promising, the application of semantic web services can be declared out of scope for present day applications due to its complexity in defining machine-interpretable knowledge, and to the great preparation effort required from process designers on computer science which could