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Survey

Semantic Web for manufacturing, trends and open issues Toward a state of the art

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ABSTRACT

Achieving success in modern industry requires the orchestration of the stakeholders of the manufacturing process as well as accessing information distributed along the manufacturing network involved; this latter is a key factor. Many manufacturing approaches have appeared with the aim of speeding up the manufacturing process by means of accessing certain knowledge encoded in a way that makes it reusable. Ontologies and the Semantic Web are emerging technologies proposed for knowledge representation and reasoning, which tend to be adopted in the manufacturing domain in order to deal and to facilitate such tasks. However, we have identified that many of the shortcomings of the proposed technologies have been neglected by some authors, compromising the feasibility of including them into any proposed approach. In this study we aim at describing the most prominent approaches which relate manufacturing with knowledge representation. Furthermore some formal aspects of Ontology and Semantic Web technologies will be introduced, with the intention of present a general view that integrates research contributions which combine both approaches in an emerging approach called Semantic Manufacturing.

1. Introduction

Nowadays, a successful enterprise requires more than low production costs to achieve success: several other variables have to be taken into account to become successful, including, for instance: customer preferences, available resources, market supply and demand, and information flow, among others. The complexity of being competitive increases when enterprises and/or the required resources are globally distributed. Thus, decision makers require having regular access to experts' knowledge of the enterprise and to have information about resources in order to take better decisions. Moreover, during the product life cycle, the required knowledge or information can have different levels of granularity, complexity and expressivity.

In the scenario outlined above, the requirement of dealing with *knowledge* becomes evident. There are several managing techniques that are implemented by managers in centralized enterprises, but representing and reusing *know-how* knowledge in distributed environments is a complex task. Here, computer-based systems are mandatory. The inclusion of such systems accelerates the workflow, grants us access to networked enterprises, databases and decreases the information processing time. Several kinds of systems have been created to date, but two main issues are still present. At first, the human intervention level is still high because knowledge for manufacturing is not fully represented in a computer interpretable manner. Furthermore, the knowledge of experts and knowledge about resources has to be accessible and reusable in a globally distributed network, like the Internet. Secondly, as several systems have been developed independently, their interaction or interoperability level for exchanging information is low.

In this vein, the ontological approach comes into play, as an approach to knowledge representation and reutilization imported from computer science. Ontology is defined as a method for knowledge representation in computer science, and Semantic Web technologies are considered as a way to make ontologies available for networks of computers. These technologies give the possibility of reasoning on asserted knowledge to infer new knowledge.

There is research related to the ontology of CAD, ontology of different resources related with manufacturing, and some ontologies of manufacturing. There are also use cases in which Semantic Web technologies have been demonstrated, giving us enough support to refer to this emerging approach as *Semantic Manufacturing*. But, some of the main issues of ontology have also been inherited into Semantic Manufacturing. To date, there is a lack of generally accepted manufacturing ontologies; there is no standard ontology for products. Moreover, ontology languages have different levels of expressivity, making necessary a careful process of evaluation for each use case.

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The research presented here aims to present the evolution of the trends most related to *intelligence* and *knowledge* in manufacturing, to introduce ontology as a convenient artifact to represent product information, enterprise knowledge and resources for manufacturing, as well as to describe how Semantic Web technologies have been used to share enterprises knowledge in networks of computers.

2. Modern approaches for industrial production processes

2.1. CAx systems

Computer Aided Design (CAD) is a field of computer science which deals with the development of virtual or digital two dimensional or three-dimensional models of objects (Papavasileiou, Gavros, Vasileiadis, & Savvidis, 2002). It has been under progressive development since the 1960s, and in the 1980s began to be accessible to middle and small sized companies, facilitating the development of new products and reducing cost in processing, distributing and sharing information about those products (Choi, Mun, & Han, 2003). This kind of software tool is now widely used for development from mechanical parts to complete assemblies of aircraft (Harik, Derigent, & Ris, 2008), cars, buildings, ships (Lee, Lee, & Roh, 2004) and submarines.

Several CAD software tools have been developed to date. AutoCAD (AutoCAD, 2010), CATIA (CATIA, 2010), Pro/ENGINEERING (Pro/Engineer, 2015), Solid Edge (Solid Edge, 2015), Free CAD (Riegel, 2011) are some of those. Most of them present a varied level of development, which is reflected in their cost and complexity. But, scenarios have appeared in which information exchange is mandatory. Thus, most CAD software vendors implemented some sort of format for data exchange. The most common formats of this kind are the Drawing Exchange Format (DXF) (Autodesk, 2009), a *de facto* standard of AutoDesk, the Initial Graphics Exchange Specification (IGES) (U.S.P.D.A., 1997) as a standard of NIST,[1] and the Standard for the Exchange of Product Model Data (STEP) (Step Tools, 2015) as a standard of ISO.[2] These exchange formats are used in many industrial applications, but with the shortcoming that no single standard is generally accepted to date, maintaining the open issue of interoperability.

Parallel to the development of CAD software tools, fabrication processes were also progressively automated. In the case of serial production of standard mechanical parts, the concept of the machine center became widely used. This consisted in integrating machine tools, such as lathes, drillers, milling machines, among others, with computer-based systems, giving rise to Computer Aided Manufacturing or CAM (Burrows, 1986). Thus, CAM has two fundamental components: first, a machine center and, second, software tools that control the machines; both components together constitute an automatic machine center (CNC) that combines the features of different machine tools at the same time. EMC CNC (Enhance Machine Controller – EMC, 2011) and Master CAM (MasterCAM, 2012) are examples of software tools for CAM.

In an integrated CAD/CAM environment, mechanical features are extracted from a CAD file, and a set of CAM instructions are developed. This task can be performed by hand or automatically, but this latter is not yet fully automated, and, depending on the complexity of the product, it still requires human intervention and adjustment even nowadays.

CAD/CAM activities are not isolated and normally they trigger other activities around them as well. That is, manufacturing planning is also required. Manufacturing process planning is a highly time consuming activity, and requires planners with good knowledge of the manufacturing facility. These experts, as human beings, have the possibility of making mistakes in the process (Semere, Dilshad, & Lindberg, 2007). Because of these factors, several Computer Aided Process Planning (CAPP) software tools have appeared on the market for commercial use, aiming at the reduction of errors and time consumption of the manufacturing process planning stage (Jain & Jain, 2001). The goal of these software tools is that, given a product (mechanical or geometric parts), machining features are recognized, machining operations and sequences are determined, and sometimes machining costs are estimated. To perform these tasks, a CAPP software tool has to read a file generated from CAD software tools in order to get the features to be machined. This first task of CAPP systems is called Automated Features Recognition (AFR). Nowadays, there are still problems to identify features from CAD files, which limits the scope of CAPP systems (Babic, Nesic, & Miljkovic, 2008).

The work of Abouel Nasr and Kamrani (2006) is an example of the prevalence of the generation of Process Planning from a digital design as a research topic. In this contribution, an Intelligent Feature Recognition Methodology was followed to recognize features from CAD files based on the IGES standard. This methodology was used to recognize features and generate a Machining Sequence Procedure. These authors outlined a proposal of an Integrated Product Development Framework as an advanced topic of work.

The benefit of CAx systems can be summarized in automation, optimization and acceleration of production. Moreover, their growth and consolidation was not isolated and has brought with them newer manufacturing philosophies that differentiate them from the traditional production line system. In the following Section these philosophies are introduced.

2.2. Concurrent Engineering for manufacturing (CE)

Concurrent Engineering (CE) is a management and manufacturing philosophy whose beginnings date back to the early 1990s (Jo, Parsaei, & Wong, 1991). It was proposed as an approach that integrates methods and technologies to facilitate the simultaneous execution of activities involved during manufacturing. CE gives preference to simultaneous execution of activities and stresses *information exchange* for decision makers. The promoters of this approach considered that it was necessary to integrate enterprise departments in a way allowing them to obtain answers to questions of what, when, where and how the manufacturing of products should be performed. CE has two main components for implementing, one related to humans and the required motivation toward this approach, and another related to the required technology to facilitate a concurrent execution of manufacturing activities.

The benefits of implementing CE in modern industry are: the increase of innovation, reduction of time to market, costs reduction, and increase of competitiveness, among others (Belay, Helo, & Kasie, 2011). Nevertheless, despite these benefits, this approach "as is" presents some shortcomings: First, it is human centered, which means it stresses the required participation and motivation for success. Second, it involves a set of technologies that were not developed for interoperability, in other words, the recommended technologies are isolated to other systems outside of the factory.

In the current scenario where an enterprise can be globally distributed with several suppliers likewise globally distributed, CE seems to have reached an inflexion point as manufacturing philosophy. Thus, it is necessary to propose a framework to allow two developments: first, to increase concurrency with these "legacy" technologies, and, second, to integrate technologies for knowledge representation, reutilization and retrieval. This second aspect is of considerable importance because here computer-based networks play a significant role while computer-based languages have a

[1] http://www.nist.gov.
[2] http://www.iso.org.