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On knowledge reuse for manufacturing systems design and planning: A semantic technology approach

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ABSTRACT

This research study deals with the early design and planning of manufacturing systems, following a knowledge reuse approach. The proposed approach introduces a knowledge based framework that facilitates the definition, storage and extraction of knowledge in terms of past production process configurations. The semantic technology and artificial intelligence approaches, such as inference rules and similarity measurement, are the main pillars of the framework. The knowledge based framework is integrated into a greater one, namely, the Virtual Factory Framework that allows for knowledge extraction from data produced by a series of software tools used during the entire factory lifecycle. The concept and the implementation are tested at the early design and planning of a steel fabrication line case study.

Introduction

In the era of a globalized and interconnected market, the manufacturing firms' survival dictates the design of production systems that present optimized performance in terms of time, cost, quality and flexibility. The numerous available process technologies, the interacting components, the intricate relationships between the performance measures and the multiple performance requirements, make the design of a manufacturing system a quite complex and challenging task [1]. Design is a knowledge intensive activity relying significantly on the experience of process engineers, industrial engineers and manufacturing equipment engineers, and demands an efficient way of managing relevant knowledge. A wealth of information lies across the different disciplines which various design engineers take advantage of during the manufacturing systems design process [2]. However, a large number of manufacturing firms declare that they are unaware of the actual extent of the knowledge that exists in their organizations [3]. It is indicative that 20% of a designer's time is dedicated to searching and analysing any available information [4,5]. Moreover, 40% of the required information is identified through personally stored information [6]. During the design stage, a set of multidisciplinary tools that make challenging knowledge storage and extraction due to existence of various data formats are used [7]. A large number of actors belonging to different departments of a company and sharing different technical background and expertise are involved in the design of a manufacturing system. The productivity, effectiveness and consistency of the actors engaged in the design phase and especially for the process planners, who are an expensive and rare resource in manufacturing, should be supported with tools leveraging knowledge management [8].

State of the art

This sub-section provides a view on the existing work of manufacturing systems knowledge management, mainly on that related to problems of design and planning. Initially, a definition of knowledge management is given and the manufacturing system's problems that can be addressed by its methods and tools are discussed. Afterwards, a series of knowledge management developments are presented and their main concepts are described. Special focus is given to the approaches that employ the semantic technology. A number of manufacturing systems ontologies and a series of frameworks that use semantics are provided. Finally, a number of issues related to knowledge management in industrial practice are identified.

Knowledge management refers to a range of practices and techniques used by organizations to identify, represent, and distribute information, knowledge, know-how, expertise and other

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forms of knowledge for leverage, utilization, reuse and transfer of knowledge across the enterprise [9]. The application of knowledge based systems to manufacturing systems design as well as to process planning, scheduling and process control was initiated almost thirty years ago. In [10] a series of knowledge based approaches used in order to address manufacturing problems is presented. The paper discusses the potentiality of these approaches and highlights the need for cooperation between computer science and manufacturing engineering for the successful development of knowledge based systems.

The concept of assembly templates focused on the automotive assembly lines was proposed in [6]. A template included information regarding processes, resources and the related key performance indicators for a range of products in a structured form. In this way, past assembly lines for a certain type of vehicles are described and stored in the form of the templates. These templates were recalled, through a case based reasoning algorithm, each time a new assembly line was designed, thus permitting the efficient reuse of knowledge in an automated way. In [8], a holistic component manufacturing process planning model was introduced. The model followed an integrated approach including technological and business data, information and knowledge and it envisioned that the model would constitute the basis for the amelioration of CAPP solutions with knowledge management and advanced decision support features. A series of guidelines concerning the classification of manufacturing knowledge for its efficient reuse were proposed in [11].

The advent of the semantic technology has led to the development of knowledge management systems [12] leveraging ontological approaches for the knowledge representation, and reuse. Moreover, semantic repositories and inference engines allowed for the efficient storage of manufacturing and facilitated a more efficient reasoning on semantic data [13]. The Manufacturing's Semantics Ontology (MASON) was based on three main concepts: entities, operations and resources. Entities dealt with data concerning products such as geometrical features, raw material and cost. Operation concepts were related to process, whereas machines, tools, human resources and plants were covered by resources concepts [14]. An approach for lifecycle management of production facilities was carried out with the use of semantic web technology in [15]. An ontology covering the lifecycle phases of a production facility from its development up to disposal also including resource, process, organization, and product areas was developed. The efficacy of the proposed approach and the introduced ontology was verified on a reuse planning case stemming from the automotive body-in-white facility. A generic ontology being the model for the knowledge representation of manufacturing systems focusing on key performance indicators was proposed in [16]. Concepts such as product, resource, process, factory, performance indicators, and their relationships constitute the core elements of the ontology. An equipment ontology, aiming to facilitate the effective design of reconfigurable assembly systems, was proposed in [17]. The specific ontology emphasized on the functional capabilities of the equipment that could be selected and integrated effectively and covered five main knowledge domains, concerning product, process, equipment. The introduced ontology was applied to a simple assembly scenario that concerned the replacement of a SCARA-type robot with a new one. In [18] an agent-based distributed manufacturing execution system dealing with production control was introduced. The proposed system also employed an ontological representation of data, belonging to the shop floor and at plant level, covering product, process, resources and operations data areas.

A knowledge framework exploiting semantic technology for semantic data storage along with similarity mechanisms and rules inference was proposed in [19]. The introduced framework was focused on supporting the early design of manufacturing systems and was verified with a simple yet real industrial case study. Towards a similar direction a collaborative knowledge based platform was described in [20]. An ontology model was used for the description of different engineering files, business processes and human resources and the platform served as a collaborative tool supporting the communication and cooperation between actors from different companies and their departments. In [21] an ontology was implemented as the basis for an agent facilitating the automated reconfiguration of a flexible manufacturing cell. The ontology served as the knowledge model of the manufacturing environment consisting of concepts such as "manufacturing operation, tool, controller, material resource" and other. The proposed agent performed reasoning based on the facts described by the ontology and made a deduction if the proposed manufacturing environment can address the given requirements. Another ontological approach supporting the manufacturing sustainability was proposed in [22]. The core of the presented ontology related to product, process, and resource concepts and to their relationships with the manufacturing sustainability. The proposed knowledge based system was capable of proposing alternatives based on the production scenario required and was applied to a facility producing air conditioning and refrigeration units for industrial and commercial use. In [23] a knowledge based design methodology for both automated and manual assembly lines was described. The methodology addressed the assembly system selection, cycle station time determination and the configuration of workstations in an automated and generic approach. The problem of product knowledge exchange for collaborative manufacturing was addressed in [24] employing, an ontology based framework. The introduced ontology consisted of smaller integrated ontologies and the framework included five elements. The domain enterprises defined the required knowledge and transformed it as a local ontology. The local ontologies of each enterprise were integrated into the global ontology. Through the latter, the enterprises could share and exchange product knowledge, leading to an increased knowledge value. The Virtual Factory Framework was an interoperable platform of heterogeneous software tools that provided support to or all the factory lifecycle phases and also employed semantic technology [45].

Knowledge management dealing with the classification of past projects lacks in companies, especially the SMEs. Product, process and infrastructure (machines and tools) knowledge was not actually managed, but it was rather only documentation performed [8]. In addition, similarity identification between new and past projects relied almost exclusively on the memory and the experience of experts. Finally, the association between the digital files of past projects produced by CAx systems, such as discrete event simulators and design software, has not been well supported.

Proposed approach

The proposed approach aims to capture, store, and retrieve knowledge relevant to the initial phases of the manufacturing system design. It intends to become a supporting tool that facilitates the automatic identification of past similar projects, whose reuse will constitute the basis for the design of a new production line. The introduced knowledge framework is integrated into the Virtual Factory Framework that incorporates a series of digital tools, used during the entire lifecycle of a factory. This integration permits the exploitation of data and files that are relevant to the production line design. The concepts of the manufacturing systems domain and their relationships are modelled with the help of a semantic data model i.e. that of ontology. Knowledge capturing is enhanced with the description of inference rules that along with ontology are stored in a