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Product design improvement through knowledge feedback of cyber-physical systems

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Abstract

In context of automation the concept of cyber-physical systems creates a consistent data interchange via open and global information networks with bidirectional flow of information. However, in order to generate potential benefits, relevant process data has to be identified and transferred to usable knowledge.
In this paper we propose an approach for using the information feedback, provided through cyber-physical systems within production facilities, for the enhancement of the product design process. Due to the integration of knowledge bases, the data gathered in production is transformed to knowledge for improvement, which is structured for re-utilization with the use of ontologies.

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Keywords: Cyber-physical systems; Product Design; Ontologies; Knowledge feedback

1. Introduction

The fourth industrial revolution and the digital transformation are prevailing factors in the manufacturing industry. Manufacturing companies are faced with changing conditions and challenges that must be responded to. These include for instance shorter product life cycles, the desire for customized products as well as increased consumer demands in terms of function, quality and design of products. Therefore, products and their design and manufacturing processes become more complex, whilst quantities are getting smaller. However, an important economic factor is a value chain with the efficiency comparable to a mass production from product design over production planning to manufacturing and service. [1]
This requires in particular a flexibilization of the largely inflexible production processes through new technologies. Cyber-Physical Systems (CPS) are considered as the most important technological enablers for the future design of the material and information flows in production and logistics. CPS enable physical objects such as machinery, conveyor systems and products to collect, store and process data as well as to communicate via digital networks with each other. [2, 3]
The results are entirely new cyber-physical production systems. Production facilities know their current technical condition, their job situation and their possible application at all times. In addition, they are able to communicate with other machines and to exchange data within the company but also beyond the company's borders. Based on the provided information an alternative value flow is determined for every product, which is optimized according to different aspects, such as quality, cost or time. [4]

However, the fourth industrial revolution concerns far more than the production process itself. It is important to consider the entire value chain. Especially the production upstream processes entail great efficiency potentials [5]. The data that is collected, exchanged and analyzed with the help of CPS forms the basis for further product and process optimization as well as complementary services.

For CPS not only play a role in the networking of individual entities with each other, they are also set as the interface between the virtual and real world. They are to merge both

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worlds seamlessly through a continuous exchange of data between real and virtual worlds. Changes in reality are directly affecting the virtual world and vice versa. In future, many production upstream processes are carried out only in the virtual world. Thus a shortening of development times and an increase in productivity are achieved. Both products and production processes should be virtually planned, tested and assured on the basis of existing data. The following examination concentrates on the use of data that can be collected by cyber-physical systems, and their added value for the knowledge-based product design. [2, 6]

2. State of the art

The product design has a high impact on the entire company. Essential decisions on factors such as quality, cost and time are made during the product design process that affect numerous other business sectors. This places high demands on the products but also to the product design process itself. The targeted use of knowledge within the product design is one of the key factors to ensure the quality and to achieve a competitive advantage.

2.1. Use of knowledge in product design

In the design process, the product layout particularly depends on the experience and creativity of developers. Usual construction and developing methods require that designers and developers continuously contribute their experience and expertise to the design process. This becomes increasingly difficult due to the increasing complexity of products, almost completely exhausted optimization potentials as well as the growing time and cost pressure. The knowledge-based approaches are able to support the product design process through knowledge that is directly saved in the CAD model or in CAD-related applications. Many modern CAD systems are based on parametric and associative and feature-based modeling approaches and offer many opportunities for the application of knowledge-based technologies like the automatic data processing in knowledge-based engineering (KBE) systems [7].

For this purpose, the existing process and product knowledge has to be identified, prepared and made available for the design process in the form of knowledge-based systems [8]. The development of a knowledge-based system for product development is divided into three main steps [9]:

1. knowledge collection
2. knowledge analysis and structuring
3. knowledge implementation

The knowledge collection is used to extract and gather knowledge from different knowledge sources. In general, a distinction can be made among three types of knowledge acquisition (see Fig. 1.). The methods of direct and indirect knowledge acquisition aim to make implicit knowledge in form of the know-how of experts available manually by himself or with the assistance of a knowledge engineer. A literature-based knowledge acquisition, for example by means of reference books, can also be assigned to the direct knowledge acquisition [10].

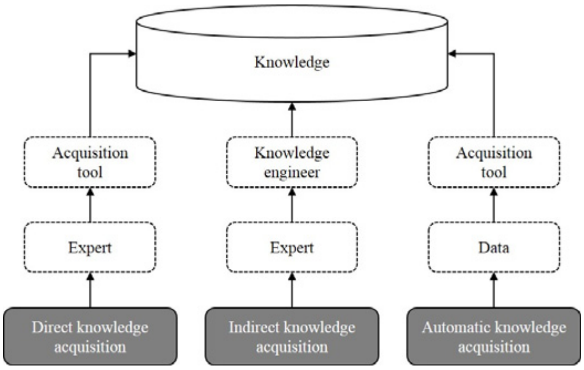

Fig. 1. Methods of knowledge acquisition [11]

Automatic knowledge acquisition approaches strive for acquiring knowledge without the aid of experts automatically by means of a self-learning system [12]. The methods of automatic knowledge acquisition can be used for various application areas [9]. This concerns, for example, the gathering of process knowledge or best practices. This issue is addressed in the further course of this paper.

Subsequently, the knowledge has to be structured and analyzed in order to prepare it for the formal integration into the knowledge base. Structures need to be developed and bases for conclusion mechanisms should be established. This is done by the definition of a lot of syntactic and semantic rules. For the analysis and structuring of engineering knowledge on behalf of the knowledge-based and computer-aided design, typical structures are [7]:

- classes with attributes, class hierarchies, taxonomies and inheritance;
- relations and constraints between entities;
- different abstraction levels (for instance, part-of hierarchies in technical systems with assemblies and parts);
- consistency conditions between various parts of knowledge.

The knowledge implementation refers to the transfer of formal knowledge on computer-interpretable knowledge carriers and the creation of appropriate applications. In connection with the product design this means the realization of a KBE application. The basis for this are existing design, procedures and solution catalogues that are taken into account and are expanded [13]. Possible knowledge carriers for the knowledge base of a KBE application are [9]:

- CAD geometries (e.g. intelligent geometry features, formula-based geometry parameters, rule-based formula linkages)
- parts lists and parts management (as a rule, with the help of a PDM system)
- specialized knowledge bases (rule and constraint libraries)
- software programs (e.g. design macros, calculation algorithms)