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Semantic hyper-graph-based knowledge representation architecture for complex product development

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ABSTRACT

More and more manufacturing companies are facing challenges in knowledge refining and reusing in stage of product development. To resolve this problem and make the knowledge convenient for acquisition, machine-understandable and human-understandable, this paper proposes a framework of semantic hyper-graph-based knowledge representation to support the knowledge sharing for the product development. A case study of car headlamp development is given to validate the feasibility and effectiveness of the proposed method. The results bring out that it can help engineers to rapidly and accurately acquire knowledge. In future research, the knowledge recommendation service based on product development process should be considered.

1. Introduction

Product development is an intensive knowledge involved, often complex, fuzzy and iterative process in product lifecycle management [1]. The needs and specifications of the knowledge is further refined over the period of product development process [2]. An efficient knowledge representation scheme can help the designer to make better-informed decisions with effective computer support tools. In today's product development field, product developers or designers need a large amount of raw data and information to perform their work. Knowledge representation is very important to convert this raw data and information into knowledge, which is available to designers [3]. There is great pressure on the product developer due to product development risk and efficiency in managing development resources, not just for the product but also for the development process. Furthermore, the trend to shorten new product development time to stay competitive has made the new methods develop fast through the use of concurrent engineering and collaborative product development processes [4], which depends on effective flow and share of knowledge between product development teams [39]. There is a common view that decisions made early in the design process have higher impact on product development time, cost, and sustainability [5]. In later stages of product development, it often requires knowledge from the earlier stages [6]. Some researches, which include design rationale systems, product families, systems engineering, and ontology engineering, pursue to capture information or knowledge from early product development decisions, customer requirements and feedback analysis reports, product functions and associated physical features. The product development knowledge generally exists and stores in management/application system or engineers' experiences [7]. Without the experience knowledge of domain experts, this kind of experience knowledge cannot be shared among engineers effectively [8].

Product development knowledge exists in technical documents, engineering manuals, design drawings and system databases [9]. It is mostly in structured or semi-structured form and stored in hard memory or information system that use for knowledge sharing and reuse [10]. In recent years, there have been significant and considerable developments in knowledge representation in product development. Some rule-based methods are not good for users to understand. The graph-based methods may lack efficiency for knowledge reasoning and storing [11]. It is useful to focus on the evolution of product development research. Then a new knowledge representation method is proposed. The knowledge representation method should be machine-understandable, human-understandable and convenient for knowledge acquisition. Therefore, a unified knowledge representation method is the premise of product knowledge service. Based on this, we present an

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approach to achieve knowledge representation for product development. The objective of this paper is therefore to propose a knowledge representation architecture which utilizes semantic hyper-graph to support the knowledge sharing throughout the product development phase.

The remainder of this paper is structured as follows. We first provide an overview of the general framework of the knowledge representation method for product development. In Section 2, we give the state-of-art review. In Section 3, we propose the classification of knowledge and classification of knowledge representation. In Section 4, we propose the process of our approach. We detailly discuss the structure of product development knowledge-service platform (PDKP), i.e. the definition of PDKP, the construction of the function and the structure of PDKP, the ontology applied in PDKP, and how to construct the relations. We propose an example to demonstrate how to integrate the PDKP and also some analysis of the approach in Section 5. In Section 6, a comparison and a discussion are provided. Furthermore, in Section 7, conclusions and potential work are included.

2. State-of-art review

2.1. Classification of knowledge

Knowledge classification is a necessary step for knowledge representation. In the research field of knowledge management of product development, knowledge can be classified into the following three dimensions.

The first dimension proposed by Nonaka is that knowledge is classified into explicit knowledge and tacit knowledge. Explicit knowledge exists in product development documents, problem-solving routines, product function and structure description, computer algorithms, technical and management systems, etc. [12]. Such knowledge consists of the intellectual platform to design and manufacture the product. On the other side, tacit knowledge is embedded in experiences, intuition, unarticulated models or implicit rules [13].

The second dimension classifies knowledge into product knowledge and process knowledge. Product knowledge includes product requirements, the mapping relationship between parts and assemblies, product/part functions, evolution-based design rationale in the product lifecycle. Based on the knowledge management processes and the main stages of the product lifecycle, the product lifecycle knowledge consists of customer knowledge, development knowledge, production knowledge, delivery knowledge and service knowledge [14].

The third dimension is defined by OECD [15] which clarifies the knowledge into four types: know-what, know-why, know-how and know-who. This dimension is one of the most important dimensions for the knowledge-based enterprises and organizations.

2.2. Classification of knowledge representation

Owen and Horváth [12] classify knowledge representation into five categories: pictorial, symbolic, linguistic, virtual, and algorithmic.

Table 1
Classification of knowledge representation.

Representation category	Example
Pictorial	Sketches, Detailed drawings, Chart, Photographs
Symbolic	Decision tables, production rules, Flowcharts, FMEA diagram
Linguistic	Customer requirements, Design rules, constraints, Customer feedback
Virtual	CAD models, virtual prototypes, multimedia, Animations
Algorithmic	Computer algorithms, Constraint solver, Design/operational procedure

Table 2
Classification of tacit knowledge representation.

Representation category	Case
Protocol analysis	Exploring problem decomposition in conceptual design [16], engineering design processes [17]
Ethnography	Role of shared artifacts [18], implementing information systems [19]
Graphic thinking	A sketch-based 3D modeling system [20], Sketch recognition in interspersed drawings [21]
Kansei engineering	Improving consumer affective satisfaction [22], User-centric design [23]
Image scale	Parameter-based product form and color design [24], innovative product design [25]

Table 1 shows the five knowledge representation methods and some examples respectively.

To support multi-domain knowledge sharing, [40] propose an object-oriented knowledge representation scheme that allows both upstream and downstream integration of CAPP, and makes it easily adaptable for interfacing with other computer integrated manufacturing modules. [41] present a causal loop model to represent causes and effects of through-life engineering service knowledge on product design. There are mainly five tacit knowledge representation methods, i.e. protocol analysis, ethnography, graphic thinking, Kansei engineering and image scale. Table 2 shows some representation forms with respect to product development for tacit knowledge in product development cycle.

The ontology approach is often used in knowledge representation. Ontology is effective in representing the structured knowledge. However, with the development of information technology, especially the application of semantic technology and Web service technology, some new methods are provided for knowledge representation. However, the industry requires a more convenient and effective method for the product development which involves various types of knowledge.

The knowledge representation method should be able to represent different types of knowledge resources in the product development process. The specific knowledge classification depends on the specific requirements of a company. However, the representation method based on hyper-graph and ontology can describe the relationships between knowledge resources and relationships, which can facilitate knowledge coding and automation. The XML Topic Map proposed in this paper is more suitable to the knowledge service environment than other methods, which can support knowledge using and sharing. Moreover, a well knowledge representation method will support product development and manufacturing and improve the use of product knowledge in new product development process.

2.3. Analysis of literature

As discussed above, the common knowledge representation methods include that semantic network-based method, neural network-based method, concept maps based-method, ontology based-method, semantic Web-based method and topic-maps based method. Table 3 shows some previous methods. This article mainly focuses on the product development in the manufacturing industry. The knowledge representation method requires some new features to adapt to this manufacturing industry environment. The product development knowledge representation model must define and represent this semantics for subsequently sharing and using product development knowledge.

According to the discussion above, the modeling method of the product development knowledge needs considering the semantic and syntax of the representation constructs. In order to develop such a