Knowledge push system based on work breakdown structure and ontology

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Abstract. The phenomenon of knowledge overflow and knowledge disorientation is very common in knowledge-intensive enterprise, even though the knowledge management system has been used. A novel knowledge push system is designed in order to push proper knowledge actively to the proper designer at the proper time, which is oriented to the product design workflow based on work breakdown structure. The ontology models of product design task and knowledge are established, and fuzzy properties are introduced into knowledge ontology model. A similarity measurement algorithm between ontology models is proposed, which generates the knowledge matching rule. Integrating ontology construction, knowledge matching rule and knowledge control model, a knowledge push system is constructed that is used to achieve precise knowledge pushing. An electronic equipment manufacturing enterprise is taken as the application case to verify the effectiveness of the system.

1. Introduction

Product design is a complex innovation process, and it has changed from experience-based to knowledge-based in recent years. As a kind of resource and invisible factor of production, knowledge is the driver to improve the production efficiency and realize the economic growth [1]. Aiming at the problem of knowledge disorientation in the existing knowledge system, it has become the focus of academic and business circles to actively push appropriate knowledge to the designers so as to improve the ability of knowledge application and innovation. Wang S F proposed a knowledge active push framework based on knowledge management and driven by workflow, in which the knowledge push rule is based on text similarity between unstructured knowledge description and design task description [2]. Yue C Y described enterprise knowledge in three dimensions: knowledge attribute, process and domain, and the knowledge is pushed by integrating knowledge score and knowledge relevance which regards domain as the link of knowledge connection [3]. Shi M H studied an implementation mechanism of knowledge push service based on dual drivers from a workflow engine and a knowledge engine, and proposed a method for active knowledge push service system which integrating human, process and knowledge [4]. Chen Y J developed an expert recommendation system for empirical knowledge based on ontology as to seek suitable consulting experts for employees who need empirical knowledge of product design [5].

The relationship between design tasks and knowledge requirements is uncertain, because of the abstractness of knowledge and the difference of designer's knowledge reserve [6]. In order to deal with this kind of uncertainty, many methods or assumptions are introduced into the area of knowledge association. Rough set has been used many times because it does not need prior knowledge or additional data when dealing with uncertain information, such as [7-8]. Ji X revealed the relationship
between design knowledge and design decision with rough set theory by collecting the usage records of design knowledge [7]. However, the interaction between knowledge push and knowledge usage record would result in narrow knowledge scope being pushed. Association rules are often mentioned in the field of knowledge. Zhang T H described the part knowledge according to the hierarchy theory of knowledge granularity and used the FP-tree algorithm to achieve knowledge association matching, however, the relationship between design task and knowledge was not analyzed [9]. Defining and refining the knowledge domain has become an important method to improve the push accuracy, without considering that some knowledge has nothing to do with the domain [3]. This assumption has been divorced from the reality of enterprise knowledge application.

In fact, not only knowledge is developing, but also the R & D process of enterprises. Design tasks are often decomposed according to the predefined work breakdown structure (WBS for short) to lay a common foundation for schedule, cost and quality control. WBS has a relatively stable and clear structure, which solves the randomness of design tasks to a great extent. Knowledge modeling based on WBS will greatly improve the accuracy of knowledge push, but the related research is still very few. This paper proposes a knowledge push method based on WBS and ontology. Firstly, the ontology models of WBS oriented design task and knowledge are established that adds semantic information to the knowledge activities in the design process. Secondly, the knowledge matching rule between ontology models is proposed. Lastly, the knowledge push control model is constructed which reveals the overall framework of knowledge push. This method takes advantage of the structured semantic model of WBS, and greatly improves the accuracy of the push contents.

2. WBS oriented ontology model of product design task

2.1. Product design task based on WBS

In essence, a WBS is a decomposition of a project scope into smaller manageable parts [10-12]. It is a hierarchical structure which is normally represented in a graphical form or in a tabular form. The WBS diagram of a piece of electronic equipment is shown in figure 1. The WBS is divided into five layers from top to bottom, which are field layer, subsystem layer, work phase layer, L1 task layer and L2 task layer. This kind of WBS is very popular in complex equipment manufacturing industry [13-14].

![Figure 1. WBS diagram of a piece of electronic equipment.](image)

**Definition 1** A work package in WBS is represented by an eight tuple:

\[
T^{WBS} = (TNO, TN, TF, TS, TP, FT, TL, TR)
\]
where $TNO$ is task number; $TN$ is task name; $TF$ is product field; $TS$ is subsystem to which the task belongs; $TP$ is work phase to which the task belongs; $FT$ is the parent task; $TL$ is task level; $TR$ is task’s ranking among its sibling tasks. $T^{WBS}$ is not yet an executable task because it also lacks some properties.

**Definition 2** A design task is represented by a seven tuple:

$$T = (T^{WBS}, TD, DC, DR, DT, TI, TO)$$

where $TD$ is task description; $DC$ is design content set; $DR$ is design restraint set; $DT$ is design target set; $TI$ is task input set; $TO$ is task output set.

Product design workflow is an ordered set of design tasks. The input and output of each design task are connected to form a network diagram including parallel structures and series structures. A product design workflow can be represented as:

$$\begin{align*}
WF & = (U, A) \\
U & = \{T_1, T_2, \ldots, T_n\} \\
A & = \{(T_i, T_j) | ti = to, ti \in TI_i, to \in TO_j, i \leq n, j \leq n\}
\end{align*}$$

where $WF$ is product design workflow; $U$ is the set of design tasks; $A$ is the set of the connections between the design tasks.

### 2.2. Ontology model of product design task

Ontology is the theoretical basis of the development of semantic web. It makes the information on web have the semantics that computer can understand. The ontology model of product design task is shown as figure 2, and only a few ontological primitives are used.

![Figure 2. Ontology model diagram of a product design task.](image)

As shown in figure 2, eleven properties are selected to describe the design task, which are mentioned in equation (1) and (2). The instance of a design task based on the ontology model can be represented by resource description framework (RDF for short) to facilitate computer processing.

### 3. WBS oriented ontology model of knowledge

#### 3.1. Knowledge activities in product design task
After receiving design task, the designer needs to solve problems with the support of design knowledge as to generate the desired output. Knowledge activity can be described as:

\[ \text{Solve}(T, K, H) \rightarrow TO \]  

(4)

where H represents the designer. Without considering the designer's knowledge background, the design task completely determines the required design knowledge. For a product design workflow based on WBS as shown in figure 1, design knowledge is closely related to WBS as well as design tasks.

**Definition 3** A piece of WBS oriented design knowledge is represented as:

\[ K = (\text{KNO}, \text{KN}, \text{KD}, [\text{KF}], [\text{KS}], [\text{KP}], [\text{KDC}], [\text{KDR}], [\text{KDT}], [\text{KI}], [\text{KO}]) \]

(5)

where KNO is knowledge number; KN is knowledge name; KD is knowledge description; KF is knowledge field set; KS is subsystem set to which the knowledge belongs; KP is work phase set to which the task belongs; KDC is design content set of knowledge; KDR is design restraint set of knowledge; KDT is design target set of knowledge; KI is input set that knowledge needs; KO is output set that knowledge can produce. Properties in brackets can be empty sets.

3.2. Ontology model of knowledge

The ontology model of design knowledge is shown as figure 3. The model structure of design knowledge and design task is similar because they are based on the same work breakdown structure. Since knowledge is abstract, knowledge items in database should be generalized. As a result, several properties which are empty sets exist in the ontology model.

![Figure 3. Ontology model diagram of a piece of design knowledge](image)

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4. Matching rule between knowledge and design task

Ontology similarity is widely concerned in ontology mapping, however, there are few researches on similarity measurement between the ontology of concrete object (design task, etc.) and that of abstract object (knowledge, etc.) [15]. Since the ontology models of design task and design knowledge are isomorphic, the similarity calculation can be expressed as the synthesis of corresponding property similarity measurement:

\[
\begin{align*}
\text{Sim}(T, K) &= \text{SimA} \times \text{SimB} \times \text{SimC} \\
\text{SimA} &= \text{Sim}(TF, KF) \times \text{Sim}(TS, KS) \times \text{Sim}(TP, KP) \\
\text{SimB} &= \omega_{\text{a}} \text{Sim}(TN, KN) + \omega_{\text{p}} \text{Sim}(TD, KD) \\
\text{SimC} &= \omega_{\text{r}} \text{Sim}(TI, KI) + \omega_{\text{p}} \text{Sim}(TO, KO) + \omega_{\text{dr}} \text{Sim}(TDC, KDC) \\
&\quad + \omega_{\text{dt}} \text{Sim}(TDR, KDR) + \omega_{\text{dt}} \text{Sim}(TDT, KDT)
\end{align*}
\]

(6)
SimA is location similarity. Both design task and design knowledge are located in the three-dimensional coordinate system established by field, subsystem and working stage. A mismatch in any dimension will result in SimA=0. Sim\((TF, KF)\) is calculated as follows, as well as Sim\((TS, KS)\) and Sim\((TP, KP)\):

$$\text{Sim}\((TF, KF)\) = \begin{cases} 1, & KF = \emptyset \text{ or } TF \subseteq KF \\ 0, & \text{other} \end{cases}$$ (7)

SimB is subject similarity. It is the similarity of design task name (or description) and design knowledge name (or description) which are in text type. The range of Sim\((TN, KN)\) and Sim\((TD, KD)\) is \([0,1]\). Notation \(\omega\) means weight, and \(\omega_i + \omega_d = 1\). There are many researches on text similarity, which will not be introduced here.

SimC is detail similarity, which represents the coverage of knowledge to design content, design restraints and design targets. Sim\((TDC, KDC)\) is calculated as follows, as well as other items in SimC:

$$\text{Sim}\((TDC, KDC)\) = \begin{cases} 1, & KDC = \emptyset \\ \frac{\text{card}\((TDC \cap KDC)\)}{\text{card}\((TDC \cup KDC)\)}, & KDC \neq \emptyset \end{cases}$$ (8)

where \(\text{card}\((\cdot)\) represents the cardinality of the set. In addition, \(\omega_i + \omega_d + \omega_{dc} + \omega_{dr} + \omega_{dt} = 1\).

Sim\((T, K)\) indicates the matching degree of design task and design knowledge, and its range is \([0,1]\). Whether a piece of knowledge is pushed is judged by a similarity threshold, which is generally recommended between 0.6 and 0.8.

5. Knowledge push control model

Knowledge push is a process of interaction between human and information system in the workflow of product design. The knowledge push control model with ontology construction and similarity calculation as the core is shown in figure 4.

![Knowledge push control model](image)

**Figure 4.** Knowledge push control model.

The process of knowledge push can be divided into six steps:

1. Convert knowledge items into ontology models in advance;
(2) Construct product design workflow based on WBS and decompose it into several design tasks;
(3) Convert the target design task into ontology model;
(4) Calculate the similarity between each knowledge ontology model and the target task ontology model;
(5) Sort the knowledge items according to the similarity scores and push the items exceeding the threshold to the designer;
(6) Select the appropriate knowledge items, and get the complete knowledge from the knowledge base.

6. Application case and comparison
An integrated design system (IDS for short) is developed based on J2EE, which is used as a design work portal in a large electronic equipment manufacturing enterprise. The system includes the WBS templates of products in various fields, which can be used to generate the design workflow for various products. A lot of knowledge ontology models are established as XML files based on RDFS, and associated with the URLs of various types of knowledge in the enterprise knowledge base. According to the knowledge push control model as figure 4, the matched design knowledge is pushed into the work page of the design task driven by the workflow. The designer clicks the knowledge item link, and the system will automatically direct to the corresponding knowledge details page in the knowledge management system (KMS for short). The related web pages are shown in figure 5.

![Figure 5. Related web pages with knowledge push.](image)

The system proposed has many advantages over the previous knowledge push system. Firstly, the ontology models of design task and knowledge add semantic information to the knowledge activities in the design process, which avoids the problem of low push accuracy caused by simple text similarity calculation with respect to [2,3,8]. Secondly, generalized representation of knowledge ontology reduces the number of knowledge items that need to be maintained, and makes knowledge description
not limited to a particular property value, such as knowledge domain [3]. Thirdly, the knowledge push rule does not depend on the historic records and avoids narrow knowledge scope being pushed, which may happen in [7, 8, 9].

7. Conclusion
This paper proposed a novel knowledge push system based on WBS and ontology. It takes the advantage of the structured semantic model of WBS and the strong semantic expression ability of ontology. The ontology models for describing concrete tasks and generalized knowledge are established. According to the characteristics of ontology models, an ontology similarity algorithm is proposed, which achieves precise knowledge matching. However, there are still many problems to be further studied, such as the push mechanism considering the knowledge level of designers.

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