REVIEW OF COMPUTER ENGINEERING STUDIES
Vol.2, No.4, 2015, pp.14-22
http://dx.doi.org/10.18280/rces.020403

KNOWLEDGE PUSH TECHNOLOGY OF COLLABORATIVE PRODUCT DESIGN BASED ON EXTENSION THEORY

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ABSTRACT

Knowledge push technology can solve such problems as low efficiency, low accuracy and timelessness in knowledge retrieval process. So far, there have been many researchers studying knowledge push in the process of product design, and they also had made a series of achievements. But in the product knowledge representation, the lack of form expression of design knowledge may thus result that knowledge push accuracy is not high and influence the push effect. For general knowledge push technology, the knowledge that each user get is the same, and unable to meet the personalized needs of users; for the knowledge push technology based on rules, it is difficult to discover rules, time consuming, and lack of explanation capacity; for the classification-excavate knowledge push technology, the learning time is long, and it is difficult to be comprehended, so it is applied only when you have plenty of time. So, this paper proposes a knowledge push technology of collaborative product design based on extension theory, and verifies it with the algorithm.

Keywords: Knowledge management, Knowledge representation, Knowledge base, Knowledge push.

1. INTRODUCTION

The modern mechanical product design process is becoming more and more complex, and it has been very difficult to complete it just by one person, so many enterprises adopt the way of collaborative design to combine many people together to complete the design. In the collaborative design process, the key factor to success is the acquisition of the past design knowledge. Although the designers can acquire knowledge by knowledge retrieval in the design process, with the knowledge base becomes bigger and bigger, designers often feel difficult to accurately obtain the knowledge related to the current design task contained in the knowledge base. At the same time, in knowledge retrieval, time consuming is also an important factor affecting the efficiency of design. However, the approach of knowledge push can greatly improve the timeliness of knowledge supply, so as to improve the efficiency of design. Knowledge push technology can solve such problems as low efficiency, low accuracy and bad timeliness etc. in knowledge retrieval process. So far, there have been a lot of researches of knowledge push on mechanical product design had been carried on, such as the architecture of product design technology push driven by workflow of Wang Shengfa [1] ect., and the mainly layer function and the manner of push had been analyzed, knowledge push method of the same design of Yang Jie [2] etc., Body Knowledge representation and push technology in the process of one certain mechanical product design of Xu Juan [3] ect.. However, in these studies, the lack of formalized expression of the content of design knowledge in the process of mechanical product design may have an effect on push effect for the expression of design knowledge is not uniform. Therefore, through analyzing the content of knowledge and the characteristics of collaborative design of mechanical products, the knowledge expression and the construction of the knowledge base of mechanical product collaborative design oriented knowledge push is studied; the structure of knowledge push system of mechanical product collaborative design is proposed and the process and realization of knowledge push are offered.

2. THE FUNCTION MODEL OF KNOWLEDGE MANAGEMENT OF PRODUCTS COLLABORATIVE DESIGN

In a specific process of task processing, knowledge is needed to reason and make decisions. System can select and match appropriate knowledge and push it to appropriate knowledge receivers from knowledge base according to the specific task and the role of task processing staff and other status information, so that the corresponding task processing personnel can use relevant push knowledge of experience, skills, principles and so on to make decisions and reasoning quickly, thus accomplishing their tasks more quickly and efficiently. Therefore, knowledge push system model driven by business process is built according to the characteristics of enterprise specific task types [4-5], as shown in Figure 1, driving by business process, when the task is processed, no matter whether it is of the same user, as long as the task is at the same characteristic, then the system will push the knowledge related to the task to the user who handle this task actively.

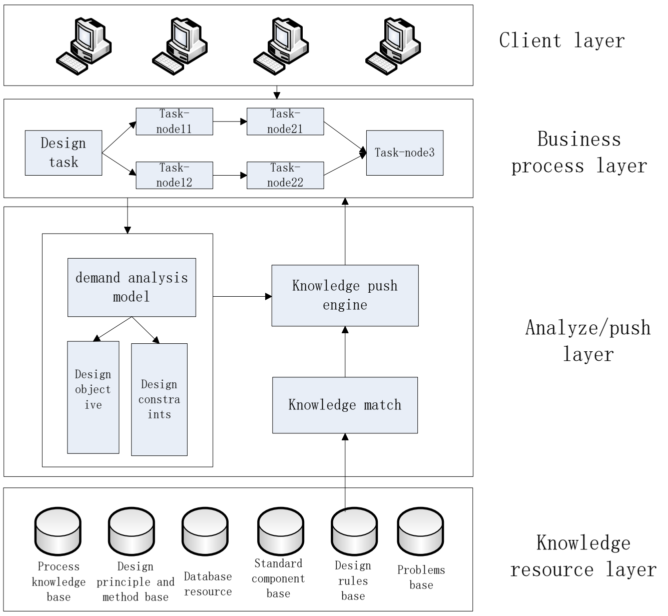

Figure 1. The model of knowledge pushing system of product collaborative design

The client layer is the port of user. Users accept a variety of tasks through the port, and the users are divided into different roles according to the difference of accepting tasks. The role is an abstract virtual member with the ability to act, and it can perform a series of business activities in accordance with the conditions and rules in a particular business environment and aiming at a particular business scope.

The business process layer manages and organizes design tasks, documents and information and so on in the process of business processing, and it is responsible for the decomposition of complex task , decomposing into the one composed of several tasks, according to the task-processing standards established by the enterprise and in accordance with the pre established procedures and rules. In the process of task processing, task-processing personnel can use the knowledge of knowledge push for specific task processing.

Analysis/ push layer is a core component of the system, and is used to push knowledge. This layer is composed of demands analysis model, knowledge matching module and knowledge push engine module. The demands analysis model is to analyze the role behaviors of user and the situational characteristics of task to get the knowledge field, knowledge subject and knowledge type etc. which the role required in solving this kind of task. All knowledge associated with the task are acquired from the knowledge base through the knowledge matching module, and finally the knowledge instances are developed by these more accurate results from knowledge matching, these knowledge instances are pushed to task-processing personnel through knowledge push engine driven by business process, task-processing staff to complete their task by using relevant knowledge of system pushing. In order to find out the suitable knowledge from the massive knowledge- related knowledge of knowledge resources management of cross regional distribution in the process of enterprise activities, such as some of the rules in enterprise production operation process- at the same time to reduce the number of matching knowledge and improve the matching efficiency, these knowledge resources must be carried on and managed effectively.

3. CONSTRUCTION OF KNOWLEDGE BASE ORIENTED PRODUCT COLLABORATIVE DESIGN

Many types of field design knowledge is included in product collaborative design process, including principle knowledge, case knowledge, experience knowledge, manual knowledge, design history knowledge, and has many performance forms such as the formula, chart, table, examples and so on. Different design knowledge have different characteristics, different design personnel have different design habits, only when the design knowledge are all expressed formally, and the design staff are regulated, the knowledge importance and the stability of knowledge base can be improved. Therefore, the extension element theory is introduced into the product collaborative design, it takes the element as a logic cell of extension design, and unifies design characteristics of quality and quantity, movement and the relationship of design objects into an ordered three tuple $\mathbf{J}=(\Gamma,c,v)$ constituted of design object Γ , design feature c and characteristic quantity value Γ of design object Γ on design feature c . From the perspective of qualitative and quantitative, information, behavior and the relationship between the process of design are provide for people to cognize the real world and solve the contradiction and reasoning in the real world. In formal modeling of various types of design knowledge based on basic element model, the formal degree of element model is higher, and combination of qualitative and quantitative expressions is adopted, the redundant information can be effectively reduced, the objectivity of the product design knowledge is more likely to be maintained [6-8].

3.1 Base element modeling of multi-type design knowledge

Multiple types of design information in the process of conceptual design is analyzed and tidied through the method of semantic segmentation, and forming minimum, complete and independent design information unit which can characterize design features, and setting up corresponding design knowledge unit according to the forms of different design information units, basic element are used for formalization and modeling description. In this paper, the design information in conceptual design is divided into the static type of design information, behavioral design information and relational design information.

When the static type of design information is modeled, the matter element model $\mathbf{J}(\mathbf{R})$ of element theory is used to describe it, if the design object to be described has n design features, the matter element model $\mathbf{J}(\mathbf{R})$ is expressed as follows:

$$\mathbf{J}(\mathbf{R})=\begin{bmatrix} \Gamma(N) & C(N)_1 & [V(C)_1, W(C)_1] \\ & C(N)_2 & [V(C)_2, W(C)_2] \\ & \vdots & \vdots \\ & C(N)_n & [V(C)_n, W(C)_n] \end{bmatrix} \quad (1)$$

Among them, $\Gamma(N)$ is the name of the described object; $V(C)$ is the value of design characteristic, $W(C)$ is the weight of design characteristic, and $V(C)$ and $W(C)$ can be many forms such as precise point value, interval value with fuzzy information, membership function and qualitative description of the semantics and so on. So, in order to express more generally, supposing $V=[v^L, v^R]$, $W=[w^L, w^R]$, both of them are interval information with fuzzy characteristics, then the formula (1) can be expressed as follows:

$$\mathbf{J}(\mathbf{R})= \begin{bmatrix} \Gamma(N) & C(N)_1 & \left([v(C)_1^L, v(C)_1^R],[w(C)_1^L, w(C)_1^R]\right) \\ & C(N)_2 & \left([v(C)_2^L, v(C)_2^R],[w(C)_2^L, w(C)_2^R]\right) \\ & \vdots & \vdots \\ & C(N)_n & \left([v(C)_n^L, v(C)_n^R],[w(C)_n^L, w(C)_n^R]\right) \end{bmatrix} \quad (2)$$

When modeling on behavioral design information, the matter element model $\mathbf{J}(\mathbf{I})$ of the element theory is used to describe it. If the design behavior described has m design features, the matter element model $\mathbf{J}(\mathbf{I})$ is expressed as follows:

$$\mathbf{J}(\mathbf{I})= \begin{bmatrix} \Gamma(D) & B(D)_1 & \left(U(B)_1,[w(B)_1^L, w(B)_1^R]\right) \\ & B(D)_2 & \left(U(B)_2,[w(B)_2^L, w(B)_2^R]\right) \\ & \vdots & \vdots \\ & B(D)_m & \left(U(B)_m,[w(B)_m^L, w(B)_m^R]\right) \end{bmatrix} \quad (3)$$

Among them, $\Gamma(D)$ is the name of describing design behavior; $B(D)$ is the operating characteristic for design behavior, $W(B)$ is the decision weight when operating characteristics is performed.

When modeling on relational design information, the relational element model $\mathbf{J}(\mathbf{Q})$ of element theory is used to describe configuration relationship, logical relationship, implicational relationship, comparative relationship, assembly relationship and so on in the design process, if the descriptive design constraint relation has k design features, the relational element model $\mathbf{J}(\mathbf{Q})$ is expressed as follows:

$$\mathbf{J}(\mathbf{Q})= \begin{bmatrix} \Gamma(S) & A(S)_1 & \left(G(A)_1,[w(A)_1^L, w(A)_1^R]\right) \\ & A(S)_2 & \left(G(A)_2,[w(A)_2^L, w(A)_2^R]\right) \\ & \vdots & \vdots \\ & A(S)_k & \left(G(A)_k,[w(A)_k^L, w(A)_k^R]\right) \end{bmatrix} \quad (4)$$

Among them, $\Gamma(S)$ is the name for describing the relationship of design constraints; $A(S)$ is the associated feature for the relationship of design constraints; $W(A)$ is the degree of correlation for the correlation features.

In the design process of complex product conceptual design, design knowledge often has a feature of mixed characteristics, that is a combination of static design information, design behavior and design constraint relationship and so on, therefore, the composite element model $\mathbf{J}(\mathbf{F})$ of basic element theory is adopted to modeled it, connecting words Θ is used to characterize the design information with multi-layer semantic and rich expression content, connect word "and" "$\wedge$" and "or" "$\vee$" etc. are connectives we used commonly, corresponding and composite element, or composite element and and-or composite element or other forms are generated, then the overall design information of project design is generated. Composite element model $\mathbf{J}(\mathbf{F})$ can be expressed as follows:

$$\mathbf{J}(\mathbf{F})= \begin{bmatrix} \Gamma(F) & (\Theta)\Gamma(\mathbf{J}(\mathbf{R}_i)) & \left(V(\mathbf{J}(\mathbf{R}_i)), W(\mathbf{J}(\mathbf{R}_i))\right) \\ & (\Theta)\Gamma(\mathbf{J}(\mathbf{I}_j)) & \left(V(\mathbf{J}(\mathbf{I}_j)), W(\mathbf{J}(\mathbf{I}_j))\right) \\ & (\Theta)\Gamma(\mathbf{J}(\mathbf{Q}_s)) & \left(V(\mathbf{J}(\mathbf{Q}_s)), W(\mathbf{J}(\mathbf{Q}_s))\right) \end{bmatrix} \quad (5)$$

Among them, i , j , s respectively express the number of matter element, thing element and relationship element of the composite element.

Here something must be emphasized is, if the above matter element model $\mathbf{J}(\mathbf{R})$, thing element model $\mathbf{J}(\mathbf{I})$, relationship element model $\mathbf{J}(\mathbf{Q})$ and composite element model $\mathbf{J}(\mathbf{F})$ are used for design knowledge modeling, just expressing a state of being rather than the importance of design attributes, the above-mentioned weight values of the basic element model will not necessarily include.

3.2 The construction of basic element extension set

In the process of product design, customer demands are divided into commonness customer demands and individuality customer demands. The commonness customer demands refers to the customers' cognitions and requirements for the product convergence, for this part of the design, product conceptual design can be achieved generally by existing typical structure or variant structure of the existing structure. Individual customer demand refers to the customers' special knowledge and requirements for the product, the conceptual design of the products are often obtained through innovating or expanding in existing product structure or function. So, in order to fully satisfy customer demand, the design process has the characteristics of dynamic, diversity, relevance and hierarchy, the existing dominant design information may not be able to fully meet the design demands, therefore, design knowledge is needed to be developed to form design knowledge set, and improve the ability of innovation in conceptual design.

From the extension of the basic element theory we know that, basic element has the characteristics of implication and extension, more rich tacit knowledge can be obtained through the extension transformation method, and generate the corresponding extension set, this provides support for the smooth implementation of the product conceptual design.

(1)Contains and base element set. For base element $\mathbf{J}_1$, $\mathbf{J}_2$,if base element $\mathbf{J}_1$ is existing, base element $\mathbf{J}_2$ must be existing, then we can say base element $\mathbf{J}_1$ contains base element $\mathbf{J}_2$, denoted as $@\mathbf{J}_1 \Rightarrow @\mathbf{J}_2$, among them, $@$ present the logo of existing. The base element can be compounded by connecting word Θ, therefore, base element implication can be characterized $@\mathbf{J}_i\Theta@\mathbf{J}_j \Rightarrow @\mathbf{J}_s\Theta@\mathbf{J}_t$, i , j , s , t present the number of base element, base element implication set can be formed by base element which can be obtained by the way of containing. Element implication can be transmitted and transformed, therefore, the process of conceptual design can be reasoned through implication.

(2) Extensibility and base element extension set. The extensibility of base element includes three aspects: divergent, expansive, and correlation. In the field of design, by extension transformation on primitive characteristics and characteristic values, on one hind, ways and methods of outward divergence and extendable design object can be established, expanding design knowledge of the field of design can be obtained; on the other hand, the relation between design objects can be established. Base element extension set $\mathbf{S}(\mathbf{J})_T$ is formed by base element which is obtained from extension transformation.

$$\mathbf{S}(\mathbf{J})_T = \Big\{(\mathbf{J},\Phi,\Psi) \mid \mathbf{J} \in T_{\Omega(J)}\Omega(\mathbf{J}), \Phi = K(\mathbf{J}) = k(X), \\ \Psi = T_K K(T_{\mathbf{J}}\mathbf{J}) = T_k k(X^*), X = c(\mathbf{J}), X^* = c^*(T_{\mathbf{J}}\mathbf{J})\Big\} \quad (6)$$

Among them, T_Ω , T_K , $T_{\mathbf{J}}$ respectively present the extension transformation of domain, correlation function, primitive features and characteristic values of the design object $\mathbf{J}$; c is the evaluation characteristics of design object $\mathbf{J}$, the quantity value is $X = c(\mathbf{J})$; c^* is the evaluation characteristics of design object $\mathbf{J}$ through the extension transformation $T_{\mathbf{J}}$, quantity value is $X^* = c^*(T_{\mathbf{J}}\mathbf{J})$; $\Phi = k(X)$ is correlation function for evaluation characteristics of the design object $\mathbf{J}$, $\Psi = T_k k(X^*)$ is the evaluation characteristic extension function of design object $\mathbf{J}$ through the extension transformation $T_{\mathbf{J}}$.

The validity of basic element extension set based on the extension transformation needs to be judged through extensional correlation function, decision process can be expressed as follows:

$$\begin{aligned} &if\ \ (\Phi = k(X) \geq 0) \vee \Big((\Phi = k(X) < 0) \wedge \big(\Psi = T_k k(X^*) \geq 0\big)\Big) \\ &then\big(\mathbf{J} \in \mathbf{S}(\mathbf{J})_T\big) \end{aligned} \quad (7)$$

The extensibility of design object provides effective support for extending and reasoning of design reuse in the process of conceptual design.

3.3 The construction of base element knowledge base

In order to make base element model of established various design information can support conceptual design better for the rapid design of complex product, knowledge base, rule base, case base, engineering database and so on which are relative to element model are needed to be established after base element formal representation of design element information unit. The similar as classical basic unit-data of relational database, the basic element will act as the basic unit to construct knowledge base of base element, rule base, case base, database etc..

Due to the knowledge source of complex product design field includes the experience of field design, design examples, the design rules and standards, design handbooks and documents, design principles and methods, demands information and related technical information, therefore, the acquirement of multiple types of design knowledge needs the help of the combining way of experts in the field-the design engineer, engineering technical personnel and knowledge engineer. The acquired knowledge needs knowledge extraction and knowledge transformation through knowledge processing system, transforming the knowledge contained in knowledge sources into the knowledge which can be deposited in the base element repository, two key steps need to be completed: the first step is forming the extracted design knowledge into knowledge unit, and can use the basic element to describe formally and modeling, the second step is transforming the design knowledge based on base element model into the internal form which can be taken advantage of by computer system directly through knowledge compilation system. At the same time, for the conceptual design of complex product, all kinds of the extracted knowledge units do not exist solely, but conducting internal or external association of design objects through the design properties, therefore, it will lead to all kinds of knowledge unit may not belong to the same level of knowledge, in order to make basic element model for effective extension transformation and contains analysis and support product conceptual design better, knowledge hierarchy and forming corresponding base element divergence set, base element extension set, base element relation set, and base element implication set is needed, then setting design knowledge a knowledge detection through knowledge compilation system, the base element is stored in the base element knowledge base. Figure 1 shows the general process and the basic framework of the construction of knowledge base of basic element.

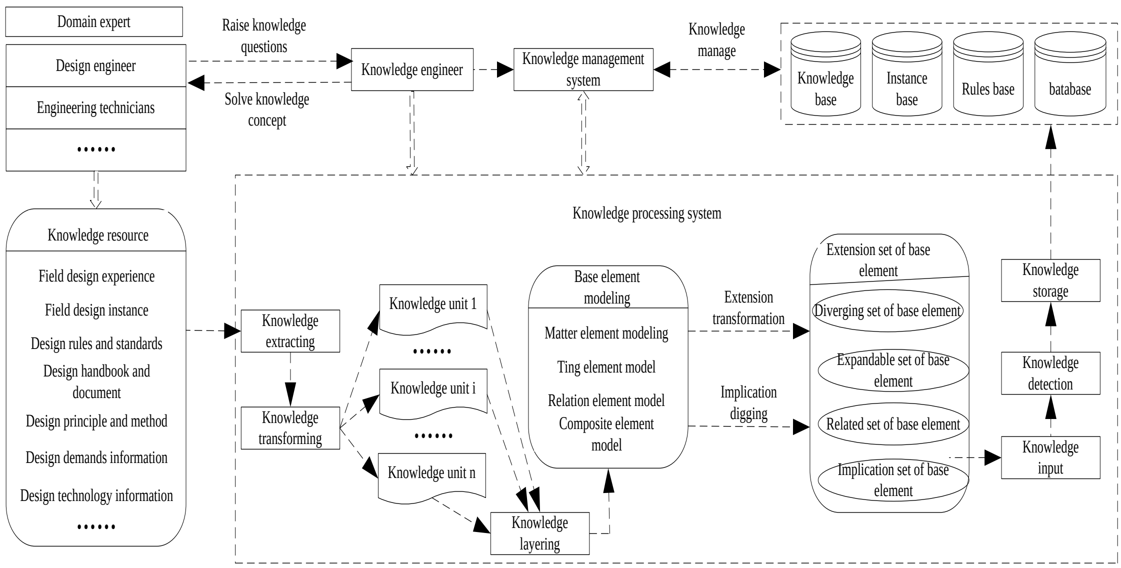

Figure 2. The general process and the basic framework of the construction of base element knowledge base

4. THE DESIGN KNOWLEDGE PUSH BASED ON EXTENSION THEORY

Extension theory is a new subject put forward by the Chinese scholar Professor Cai Wen, in the classical mathematical theory, when the points are in the internal, classical mathematics consider their distance is zero, while the concept of distance was quoted in the extension theory, the different position of the point can be described according to the different distance [9-12]. In the algorithm of knowledge push, when a certain few of design knowledge is associated with design constraints, the traditional algorithm can't depict which knowledge between them is more accordance with the demands of designers, but the specific correlation between each knowledge and constraints can be detailed depicted after introducing the concept of extension distance, the relevant design knowledge which is most consistent with designers need can be identified, therefore, this paper introduce the extension theory into knowledge push to increase the accuracy of knowledge push.

4.1 Designing the extension model of knowledge push

For the knowledge base of base element $U=\{J\}$, assuming $c_0=(c_{01},c_{02},\cdots,c_{0m})$ as m constraint conditions for the design task, the value of the base element J concerning c_0 is

$$c_0(J)=\left(c_{01}(J),c_{02}(J),\cdots,c_{0m}(J)\right)\overset{\Delta}{=}\left(x_1,x_1,\cdots,x_m\right) \tag{8}$$

$V(c_{0i})$ is the value range of X_{0i}, X_{0i} is positive domain, $X_{0i}\subset V(c_{0i})$, establishing correlated function $k_i(x_i), i=1,2,\cdots,m$,

$$\begin{aligned}k\left(c_0(J)\right)&=\left(k_1\left(c_{01}(J)\right),k_2\left(c_{02}(J)\right),\cdots,k_m\left(c_{0m}(J)\right)\right)\\&=\left(k_1(x_1),k_2(x_2),\cdots,k_m(x_m)\right)\end{aligned} \tag{9}$$

This correlated function is the decision vector of knowledge push J.

$$K(J)=\sum_{i=1}^{m}\alpha_i k_i\left(c_{0i}(J)\right)=\sum_{i=1}^{m}\alpha_i k_i(x_i) \tag{10}$$

is the comprehensive association degree of J regarding c_0, and

$$\tilde{E}(J)(T)=\left\{(J,Y,Y')\mid J\in T_U U, Y=K(J)\in \mathrm{I}, Y'=T_K K(T_J J)\in I\right\} \tag{11}$$

is the extension base element set with multi constraint characteristics on U, if the weight coefficient of each constraint condition of the design task is $\alpha_1,\alpha_2,\cdots,\alpha_m$, and it meets $\sum_{i=1}^{m}\alpha_i=1$.

In the formula, T_U, T_K, T_J are the extension transformation for domain U, correlation function K, and the knowledge base element J.

For the constraint conditions c_0, if c_{0i} is the constraint condition which the design task must meet, the first screening should be conducted carefully by constraint condition c_{0i} for all the knowledge of base element, then basic element model of fuzzy evaluation about constraint c_0 is established on screening knowledge, and establish extension comprehensive correlative degree about constraints.

In the calculated comprehensive extension relational degree of each element on the constraint condition, for a certain knowledge base element J_i, if $K(J_i)>0$, then considering knowledge element J_i satisfies the design constraints, which can be pushed to the related design personnel; if $K(J_i)<0$, then the knowledge base element does not satisfy the design constraints, which can not be pushed to the design personnel; if $K(J_i)=0$, then whether it is need to be pushed to the design personnel is according to the actual situation.

If base element J_0 satisfies

$$K(J_0)=\max_{1\le i\le n}\{K(J_i), J_i\in U\} \tag{12}$$

it represents the comprehensive correlative degree J_0 is maximum, the degree meeting the comprehensive requirements is highest, so the degree which knowledge base element J_0 satisfies the knowledge demands of designer, then it can be pushed to the design personnel.

4.2 The fuzzy matter-element model of the decision of knowledge push

Assuming a knowledge base element in the knowledge base is J_p, its matter-element model can be constructed according to the existing constrain characteristic c_0. For knowledge base element under given constraint characteristics may have some uncertainty design information, therefore, the feature value of its corresponding constraint feature is often fuzzy, accurate value can be used to describe the feature information which can be represented accurately, for the feature value containing uncertainty design information, range value can be used to describe it, at the same time, it has different preferred characteristics weights, therefore, the fuzzy matter element model of knowledge based element J_p is expressed as $\mathbf{R}_p$:

$$\mathbf{R}_p=(J,C,V)=\begin{bmatrix} J_p & c_{01} & \left(\left[v_1^{1p}(c_{01}),v_2^{1p}(c_{01})\right],\alpha_1\right) \\ & c_{02} & \left(\left[v_1^{2p}(c_{02}),v_2^{2p}(c_{02})\right],\alpha_2\right) \\ & \vdots & \vdots \\ & c_{0m} & \left(\left[v_1^{mp}(c_{0m}),v_2^{mp}(c_{0m})\right],\alpha_m\right) \end{bmatrix} \tag{13}$$

Among them, $V_{ip}(c_{0i})=\left[v_1^{ip}(c_{0i}),v_2^{ip}(c_{0i})\right]$ is the range value taken from determine knowledge base element J_p for the number i constraint, namely it is the classical field on this condition feature, α_i is the weight of the number i constraint feature, and it meets $\alpha_1+\alpha_2+\cdots+\alpha_m=1$.

$V_i=\left[v(c_{0i})^L, v(c_{0i})^R\right]$ is the value range taken from all knowledge base element J on constraint characteristics c_{0i} in knowledge base, named joint domain, and meeting $v(c_{0i})^L=\min_{1\le j\le n}\left(v(c_{01})_j^L\right)$, $v(c_{0i})^R=\min_{1\le j\le n}\left(v(c_{01})_j^R\right)$.

4.3 The construction of extension correlation function of knowledge push

If you want to get the comprehensive related degree of knowledge base element J_p on the constraint conditions c_0, extension distance, extension correlation function and extension related degree between J_p and corresponding constraints are needed to be established.

For analyzing the degree of correlation between the each optimized decision index and the corresponding classical domain and joint domain, extension distance, extension correlation function and extension related degree between decision index and the corresponding classical domain and joint domain are needed to be established.

The value of knowledge base element J_p on the constraint conditions c_0 is:

$$\begin{aligned} c_0(J_p)&=\left(c_{01}(J_p),c_{02}(J_p),\cdots,c_{0m}(J_p)\right) \\ &=\left([v(c_{01})_p^L,v(c_{01})_p^R],[v(c_{02})_p^L,v(c_{02})_p^R],\cdots,[v(c_{0m})_p^L,v(c_{0m})_p^R]\right) \end{aligned} \tag{14}$$

According to extension-distance calculation formula:

$$\rho(v,X)=\left|v-\frac{x_1+x_2}{2}\right|-\frac{1}{2}(x_2-x_1) \tag{15}$$

Bring the number i value $c_{0i}(J_p)$ of knowledge base element J_p on the constraint condition c_0 and the classical field range $V_{ip}(c_{0i})=\left[v_1^{ip}(c_{0i}),v_2^{ip}(c_{0i})\right]$ on the number i constraint into the formula (15) and get the the classical field extension distance of constraints characteristics c_{0i} on J_p:

$$\begin{aligned} &\rho\left(c_{0i}(J_p),V_{ip}(c_{0i})\right)= \\ &\frac{1}{2}\left(\rho\left(v(c_{0i})^{pL},V_{ip}(c_{0i})\right)+\rho\left(v(c_{0i})^{pR},V_{ip}(c_{0i})\right)\right) \end{aligned} \tag{16}$$

Bring the number i value $c_{0i}(J_p)$ of knowledge base element J_p on the constraint condition c_0 and the classical field range $V_i=\left[v(c_{0i})^L,v(c_{0i})^R\right]$ on the number i constraint into the formula (15) and get the the classical field extension distance of constraints characteristics c_{0i} on J_p:

$$\begin{aligned} &\rho\left(c_{0i}(J_p),V_i\right)= \\ &\frac{1}{2}\left(\rho\left(v(c_{0i})^{pL},V_i\right)+\rho\left(v(c_{0i})^{pR},V_i\right)\right) \end{aligned} \tag{17}$$

The extension correlation degree of knowledge base element J_p on constraints c_{0i} can be expressed as $k_i\left(c_{0i}(J_p),V_{ip}(c_{0i})\right)$:

$$\begin{aligned} &k_i\left(c_{0i}(J_p),V_{ip}(c_{0i})\right)= \\ &\begin{cases} \dfrac{\rho\left(c_{0i}(J_p),V_{ip}(c_{0i})\right)}{\rho\left(c_{0i}(J_p),V_i\right)-\rho\left(c_{0i}(J_p),V_{ip}(c_{0i})\right)+v_1^{ip}(c_{0i})-v_2^{ip}(c_{0i})} & c_{0i}(J_p)\in V_{ip}(c_{0i}) \\ \dfrac{\rho\left(c_{0i}(J_p),V_{ip}(c_{0i})\right)}{\rho\left(c_{0i}(J_p),V_i\right)-\rho\left(c_{0i}(J_p),V_{ip}(c_{0i})\right)} & c_{0i}(J_p)\notin V_{ip}(c_{0i}) \end{cases} \end{aligned} \tag{18}$$

For each constraint characteristics c_{0i}, the weight coefficient α_i, and meet $\alpha_1+\alpha_2+\cdots\alpha_n=1$, then the comprehensive correlative degree of knowledge basic element J_p about the constraint c_0:

$$K(J_p)=\sum_{i=1}^{m}\alpha_i k_i\left(c_{0i}(J_p),V_{ip}(c_{0i})\right) \tag{19}$$

5. THE EXTENSION PROCESS OF KNOWLEDGE PUSH

The process of knowledge push based on the structure of knowledge management system, as shown in Figure 3.

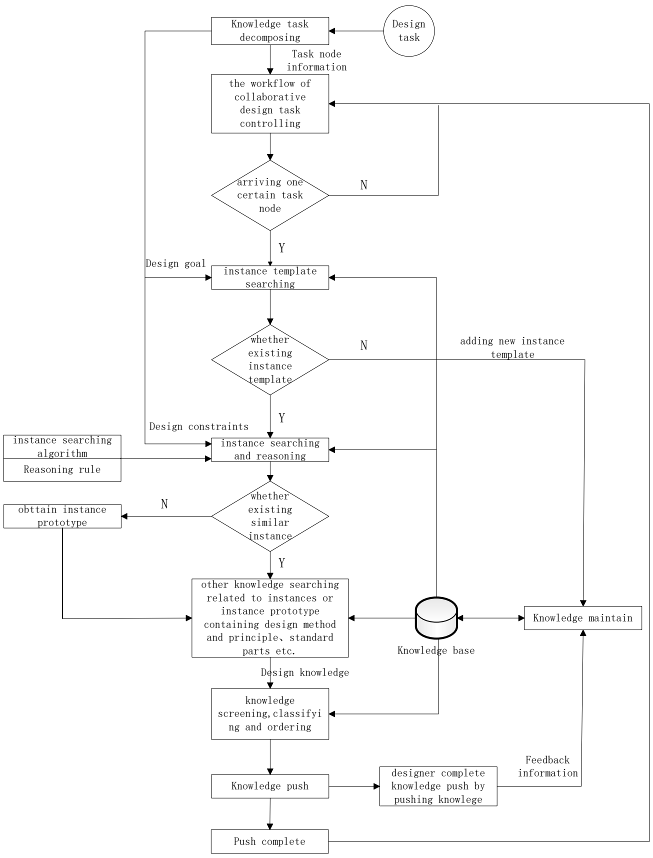

Figure 3. The flow chart of knowledge push in mechanical product collaborative design

The whole process can be carried out according to the following steps:

Step1 Decompose the design tasks and arrange appropriate designer for one task or subtask. For a task node, existing the corresponding design objectives, constraints, initial conditions and design personnel after the task is decomposed.

Step2 In the process of collaborative design, the procedure is needed to be controlled, when the procedure reaches a task node, steer (3), if the procedure is between two task nodes, knowledge push should not be carried on, continuing to monitor the procedure.

Step3 Search instance template according to the task goal of one certain design nodes, if there is no instance template, it illustrates there is no the design instance corresponding current design task in the knowledge base, at this time, the system will not push knowledge to designers, and prompt increasing new instance template, return (2).

Step4 Search the instance which is most similar to current design by instance retrieval algorithm, based on the retrieval success of instance template, if there are similar examples, then reasoning according to the rules of reasoning, and steering (6), if not, turn to (5).

Step5 Obtain an instance prototype, instance prototype is the formal description of similar design examples, for one certain instance template, there are the only case prototype corresponding with it.

Step6 retrieves related design principles and methods, design rules, standard parts and other knowledge according to the similar instances or the instance prototype of(5)retrieved from (4).

Step7 Screen, classify and sort the design knowledge retrieval.

Step8 Push knowledge to the designer in the current design task, and maintain the knowledge according to the knowledge push application of designers.

Step9 Complete the knowledge push under the current task, returning (2).

6. APPLICATION EXAMPLEA

This paper takes the runner design of a hydropower station as an example, and illustrates the knowledge push technology based on the extension theory in detail. The fuzzy constraint characteristics of the hydropower Station runner is got through the decomposition and calculation of design tasks, its value is given in the form of interval values: rated head: 55~60m, rated power: 320~330MW, rated flow: 570~590m3/s. the weight of such characteristics as rated head, rated power and rated flow of constraint characteristics is determined according to the expert method, the weights are 0.4, 0.4, 0.2.

Conduct a preliminary screening of base element instance database According to the key constraint characteristics of the runner, screening out the base element instance of turbine runner in the instance database. Due to the wheel instance in the case database is large, and not all of them can be illustrated, this paper selects six function element instance of the runner of Wuqiangxi, Yantan, Geheyan, Baishan, Gezhouba Dam Three Gorges in the base element instances of preliminary screening, their functional base element model respectively are J_1 , J_2 , J_3 , J_4 , J_5 and J_6 , as follows:

$$J_1=\begin{bmatrix} \text{runner} & \text{rated head（m）} & 44.5 \\ & \text{rated power(MW)} & 248 \\ & \text{rated flow}(\mathrm{m}^3/s) & 625.3 \\ & \text{rated speed(r/min)} & 68.18 \\ & \text{efficiency} & 95\% \end{bmatrix};$$

$$J_2=\begin{bmatrix} \textit{runner} & \textit{rated}\ \text{head（m）} & 59.4 \\ & \textit{rated}\ \text{power(MW)} & 302.5 \\ & \textit{rated}\ \text{flow}(\mathrm{m}^3/s) & 580 \\ & \textit{rated}\ \text{speed(r/min)} & 75 \\ & \textit{efficiency} & 94.4\% \end{bmatrix};$$

$$J_3=\begin{bmatrix} \textit{runner} & \textit{rated}\ \text{head（m）} & 103 \\ & \textit{rated}\ \text{power(MW)} & 300 \\ & \textit{rated}\ \text{flow}(\mathrm{m}^3/s) & 326 \\ & \textit{rated}\ \text{speed(r/min)} & 136.4 \\ & \textit{efficient} & 94.4\% \end{bmatrix};$$

$$J_4 = \begin{bmatrix} runner & rated\ \text{head（m）} & 112 \\ & rated\ \text{power(MW)} & 300 \\ & rated\ \text{flow}(\text{m}^3/s) & 307 \\ & rated\ \text{speed(r/min)} & 80 \\ & efficient & 93.5\% \end{bmatrix};$$

$$J_5 = \begin{bmatrix} runner & rated\ \text{head（m）} & 177 \\ & rated\ \text{power(MW)} & 607 \\ & rated\ \text{flow}(\text{m}^3/s) & 886 \\ & rated\ \text{speed(r/min)} & 135 \\ & efficient & 94.21\% \end{bmatrix};$$

$$J_6 = \begin{bmatrix} runner & rated\ \text{head（m）} & 114 \\ & rated\ \text{power(MW)} & 300 \\ & rated\ \text{flow}(\text{m}^3/s) & 543 \\ & rated\ \text{speed(r/min)} & 144 \\ & efficient & 93.11\% \end{bmatrix}.$$

Conduct fuzzy matter element model of decision of the runner base element instance according to the formula (11):

$$\mathbf{R}_p = (J_i, C, V) = \begin{bmatrix} J_i & rated\ \text{head}(m) & ([55,60],0.4) \\ & rated\ \text{power}(MW) & ([320,330],0.4) \\ & rated\ \text{flow}(m^3/s) & ([570,590],0.2) \end{bmatrix},$$

$i = 1 \sim 6$;

The classical domain of knowledge base element J_i on $c = (c_1, c_2, c_3) = (rated\ \text{head}(m), rated\ \text{power}(MW), rated\ \text{flow}(m^3/s))$ is $V_1 = (V_{11}, V_{22}, V_{33}) = ([55,60],[320,330],[570,590])$, the section field of knowledge base element J_i on c is $V = (V_1, V_2, V_3) = ([44.5,177],[248,607],[307,886])$

By the formula (15), bring the characteristic value and classical field V_{11} of function base J_1 on constraint characteristic into the formula (15) to obtain the classic extension distance of c_1 on J_1

$$\rho(c_1(J_1), V_{11}(c_1)) = \left|v - \frac{x_1 + x_2}{2}\right| - \frac{1}{2}(x_2 - x_1) = \left|44.5 - \frac{55+60}{2}\right| - \frac{1}{2}(60-55) = 10.5$$

By the formula (16), bring the characteristic value and section field V of function base J_1 on constraint characteristic into the formula (15) to obtain the classic extension distance of c_1 on J_1

$$\rho(c_1(J_1), V_1(c_1)) = \left|v - \frac{x_1 + x_2}{2}\right| - \frac{1}{2}(x_2 - x_1) = \left|44.5 - \frac{44.5+177}{2}\right| - \frac{1}{2}(177-44.5) = 0$$

Bring the classical domain extension distance and joint domain extension distance into the formula (18), and obtain the extension correlation degree $k_1(c_1(J_1), V_{11}(c_1)) = -1$ of knowledge base element J_1 on the constraints c_1.

Similarly, we can calculate the extension relation degree k_2, k_3 of knowledge base element J_1 on the constraint c_2, c_3 respectively -1, -1.08.

Bring the constraint feature weight coefficient $\alpha = (\alpha_1, \alpha_2, \alpha_3) = (0.4, 0.4, 0.2)$ and the extension correlation degree k_1, k_2, k_3 of knowledge base element J_1 on the constraints c_i into the formula (19), and obtain the comprehensive correlative degree of knowledge base element k_3 on the constraint condition c:

$$K(J_1) = \sum_{i=1}^{3} \alpha_i k_i (c_i(J_1), V_{i1}(c_i)) = -1.016$$

Similarly, we can calculate the comprehensive correlative degree $K(J_2)$, $K(J_3)$, $K(J_4)$, $K(J_5)$, $K(J_6)$ of the knowledge base element J_2, J_3, J_4, J_5, J_6 of runner , and the result are respectively 0.276, 0.088, 0.116, -0.466, -0.864. Order the 6 runner element by the comprehensive correlative degree is $K(J_2) > K(J_6) > K(J_4) > 0 > K(J_3) > K(J_5) > K(J_1)$. So the knowledge base element J_2, J_6, J_4 satisfy the constraints, if set the number of the knowledge push base element 2, then it will push the base element instance of Yantan runner and Gezhouba Dam runner to designers in order.

7. CONCLUSIONS

This paper analyzes the problems of the management of current collaborative design knowledge, and offers the structure of the knowledge push system of collaborative product design. Aiming at the limitation of several knowledge representation such as relationship representation, frame representation, production representation etc. in knowledge management relationship, take base element as the basic element to describe the product design knowledge, carry on formal form expression, establish extension knowledge base, improve the reuse of knowledge and the stability of knowledge base. Based on the extension knowledge base, put forward knowledge push algorithm of collaborative product design based on the extension theory, and finally illustrated by the knowledge push of the power station turbine design, verify the effectiveness of the algorithm.

ACKNOWLEDGMENT

This research was supported by the National Natural Science Foundation Youth Fund of China (No. 51005114); The Fundamental Research Funds for the Central Universities, China (No. NS2014050);The Research Fund for the Doctoral Program of Higher Education,China(No. 20112302130003); Jiangsu Planned Projects for Postdoctoral Research Funds (No. 1301162C).

REFERENCES

[1] Wang Shengfa, Gu Xinjian, Guo Jianfeng, et al. "The study of active knowledge push oriented product design [J]," *Computer Integrated Manufacturing Systems*, 2007, 13 (2).

[2] Yang Jie, Yang Yu, Wang Weili, et al. "The study of knowledge push method of collaborative product design based on rough set [J]," *China Mechanical Engineering*, 2009, 20 (20): 2452-2456.

[3] Xu Juan, Hu Jie, Zhou Fei, et al. "Knowledge representation and push in the process of cold roll form design [J]," *Machinery Design and Research*, 2008, 24 (2).

[4] Wang Youyuan, Wang Falin, Le Chengyi, etc. "Knowledge modeling of multi-group design team collaborative product design based on techontology [J]," *Chinese Mechanical Engineering*, 2012, 23 (22): 2720-2725.

[5] Zhang Mei, Hao Jia, Yan Yan, et al. "Knowledge modeling technology based on ontology [J]," *Journal of Beijing Institute of Technology*, 2012, 30 (12): 1405-1431.

[6] Li Yang, Xie Guangqiang, "The formal representation and implementation of extension base element," *Software Guide*, 2013,12 (7): 37-39.

[7] Cai Wen, Yang Chunyan, "Basic theory and methodology system of extenics," *Science Bulletin*, 2013, 58 (13): 1190-1199.

[8] Zhong Shisheng, Zhang Yan, "Representation of extension knowledge and the development of knowledge base system [J]," 2008,14 (11): 2184-2190.

[9] Ti-chun Wang, Ai-jun Yang, Shi-sheng Zhong, Zhen-dong Zhao, "Extension adaptive design model of scheme design for complex mechanical products [J]," *Tehnički vjesnik/Technical Gazette*, 2014, 21(1): 123-133.

[10] Ti-chun Wang, Ai-jun Yang, Shi-sheng Zhong, "Multi-attribute extension fuzzy optimized decision-making model of scheme design [J]," *Tehnički vjesnik/Technical Gazette*I, 2014,21(2) : 239-247.

[11] Y. W. Zhao, G. X. Zhang, "A new integrated design method based on fuzzy matter-element optimization [J]," *Journal of Materials Processing Technology*, 2012, 129(1-3): 612-618.

[12] JIA Chun-rong, ZHANG Jun, "Evaluation of regional circular economy based on matter element analysis," *Procedia Environmental Sciences*, 2011,11: 637-642.