Process Knowledge Recommendation System for Mechanical Product Design

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ABSTRACT To solve the problems of high time cost caused by the low efficiency of knowledge acquisition, this paper proposes a knowledge service framework based on case set. Three knowledge retrieval methods are designed based on parts keywords, customer orders and manufacturing processes. Additionally, a VSM-based(vetor space model) knowledge recommender method is proposed by using similarity matching algorithm to improve the efficiency of knowledge acquisition and transfer. Finally, application scenarios and evaluation of the proposed approach in a mechanical product design project are given to illustrate the application effect of knowledge service system.

INDEX TERMS Product development, Process knowledge, Knowledge sharing, Knowledge recommendation, Knowledge-based service system

I. INTRODUCTION

With the ever-growing in the next generation technology trends, the manufacturing industry is realizing the importance of knowledge in having a competitive advantage over its competitors. Therefore, the approach of knowledge acquisition to drive product innovations is crucial in enhancing the competitiveness [1]. In the fields of mechanical manufacturing, a product generally can be categorized into design and manufacturing systems or functional modules. The product development processes require a collaboration method integrated with knowledge acquisition and sharing [2]. As such, the existed process knowledge has been seen as the most useful and valuable resource to support product development. Process knowledge here mainly refines from process data, tools and documents of product development, product design cases. Since it would be taken a long term for an engineer to be an expert. One of the challenges for manufacturing firms is the shortage of knowledge domain experts. As such, it is a big challenge for most manufacturing companies to industrial transformation and upgrading. New knowledge sharing and reuse approaches need to propose to resolve this problem. Knowledge recommender technologies are now becoming a new research trend for knowledge reuse.

From the annual Global Most Admired Knowledge Enterprises (MAKE) [3], the organizations have been recognized as leaders in effectively transforming enterprise knowledge into wealth-creating ideas, products, and solutions. Following these examples, more enterprises start to learn the knowledge acquisition and reuse methods to support product development. As one of the most valuable intangibles for the enterprises, product knowledge can provide a better support work for users' product design. Therefore, knowledge reuse and sharing can be seen as the value-added action in product development process [4]. On the other side, engineers have to learn and practice for a long term before becoming domain experts. Therefore, a new knowledge service method should be proposed for product development and manufacturing to boost the efficiency of product design, reduce the time-cost.

After the introduction, the rest of this paper is structured as follows. The related work of this research is provided briefly in Section 2. Section 3 proposes a process knowledge service model for product design. Section 4 develops a knowledge recommender model. After that, a process knowledge recommendation method is proposed in Section 5. Section 6 provides a case study to show and demonstrate the implementation of the proposed method. Finally, Section 7 summarizes the conclusions and future research.

II. RELATED WORK

Knowledge service is a knowledge sharing method based on knowledge representation, retrieval, recommendation and

application. It can be integrated into the product development processes to solve the engineers' knowledge demands, and to provide effective support for product innovation [5]. Recently, many different sectors conduct knowledge service system to provide knowledge services for knowledge sharing, acquisition, reuse, recommendation and innovation [6, 7]. Especially, under the perspective of product life-cycle, many researchers focus on how to use the knowledge service methods in collaborative product development teams [8,9,10,11] and new product development [12,13,14,15]. For the rest stages of product life-cycle, the research concern of knowledge sharing framework and method are focused on socialization mechanisms product development teams [16,17,18], product-service system development (PSS) [19,20], product supply chain management [21, 22, 23] and outsourcing projects of software product [24].

In addition to the above knowledge reuse methods, the research of knowledge sharing has been integrated with new emerging technologies. The global dimension and tools for both academic and industry have been validated its availability in different sectors. Wu et al. [25] discuss and define cloud-based design and manufacturing. Peng et al. [26] develop a framework to support design knowledge representation, retrieval, reasoning and fusion. Zammit et al. [27] add to existing research on PD testing procedures in a UK-based manufacturing plant. Chhim et al. [28] present an ontology-based model for manufacturing knowledge reuse. Yin and Xiong [29] propose a cognitive theory based method to classify design knowledge.

Indeed, knowledge recommender technologies have revealed a new trend for product development knowledge sharing [30,31]. Zhen et al. [32,33] propose a novel knowledge recommender method among a collaborative team. Choi [34] derives the implicit ratings to be applied to online transaction data for improving knowledge recommendation quality. Verma et al. [35] develop a recommendation platform to help users in discovering useful knowledge. Yan et al. [36] present a context-based recommender model to identify the relationship between knowledge and engineers. Su et al. [37] present a knowledge recommendation framework based on complex event process to realize knowledge intelligent recommendation. Mishra et al. [38] propose a knowledge recommender system considering sequential information present. Liu et al. [39] propose a workflow-based context matching method to evaluate relationship between workflow contexts and exploit it for knowledge recommendation. Song and Zhan [40] develop the knowledge recommendation process by using a Gantt chart to show the time-sequence relationship.

The extant literature as shown above, almost all researchers study on knowledge transfer and reuse in collaboration development team. Some studies use new technologies including cloud computing and social media. However, few studies consider the complex and iterative process in product development. Actually, product development is a knowledge intensive process that require a large number of specifications and knowledge. Therefore, it is a trend to propose a knowledge recommendation method to support engineers. As such, this study uses the vetor space model by using similarity matching algorithm to improve the efficiency of knowledge acquisition and transfer.

III. A KNOWLEDGE SERVICE FRAMEWORK BASED ON CASE SET

Actually, different industries may have different knowledge service requirements in product development. According to the characteristics of parts design and manufacturing in mechanical manufacturing enterprises, process knowledge can be mapped a point-to-point relationship into parts development. Two key technologies should be considered before integrating knowledge service with product development. Firstly, the method of knowledge service can provide knowledge for engineers to improve the knowledge flow and create value for product development. Knowledge service methods can also merge with expert knowledge, domain knowledge and other integrated knowledge model and system. These kinds of knowledge would be transferred to different team members. It would structure and systematize enterprise knowledge to realize knowledge innovation. Another key technology should focus on the knowledge acquirement method. Knowledge reuse is an important value-added process to make knowledge acquisition more efficiently. The general method of knowledge acquisition is knowledge retrieval and knowledge recommendation. The acquisition efficiency is generally improved by using the information integrated technology. To meet the knowledge requirement depicted above, a knowledge service framework is proposed based on the knowledge-mapping model from parts development to process knowledge as shown in Figure 1. This framework of knowledge service can integrate with mechanical product development processes. It can also support the mechanical product development and make the knowledge service more instantiated and concrete.
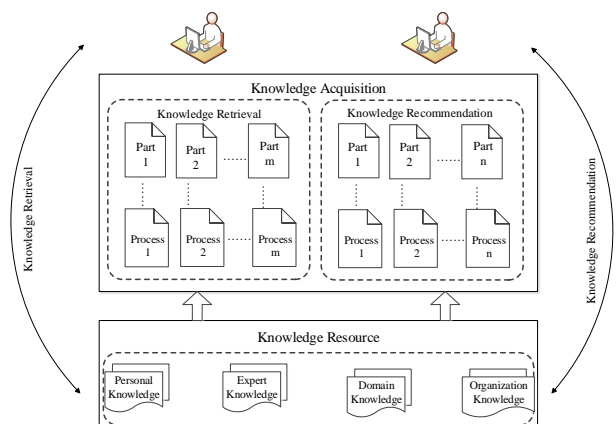

FIGURE 1. Case set-based framework of knowledge service.

IV. SUPPORTING TECHNOLOGIES FOR PROPOSED FRAMEWORK

Knowledge sharing can solve partly the low utilization and efficiency of knowledge in the enterprise. Knowledge sharing can help to realize an intelligent semantic understanding of information through knowledge flow and knowledge representation technology. The knowledge, which existed in the mapping relationship between different knowledge entities, can also be used to improve the efficiency of product development. The efficiency of knowledge acquisition directly affects product development to reduce the production time cost.

During mechanical parts development, engineers need to get right knowledge according to product development requirements. In this paper, three methods of knowledge

retrieval are proposed, considering the engineers knowledge requirements, as shown in Figure 2. The definition of knowledge retrieval refers to the search for the existed and formed knowledge resources. When an engineer retrieves the machined processing of a part, some supporting knowledge would also be provided to engineer. This knowledge sharing method can ensure the relevance and consistency between parts and process knowledge. It can reduce the knowledge search time cost for engineers, enable knowledge retrieve easily, enhances the system flexibility and the effectiveness of knowledge reuse, improve greatly the efficiency of knowledge acquisition.
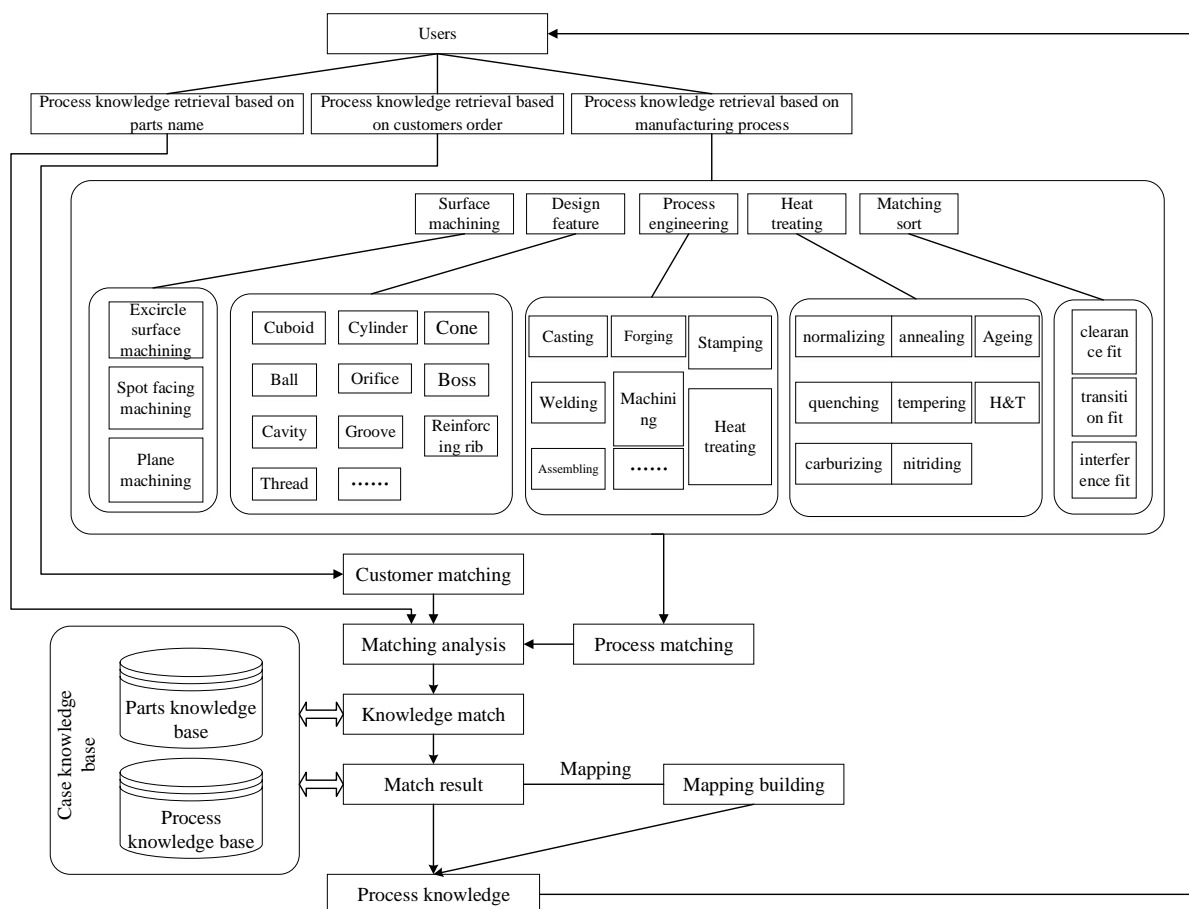

FIGURE 2. Knowledge sharing process based on case set.

A. PROCESS KNOWLEDGE RETRIEVAL METHOD BASED ON KEYWORDS

This method uses the keyword to match parts and process knowledge stored in the knowledge repository. The operation steps of this method include keywords analyzing, disaggregating, and matching with process knowledge. Knowledge retrieval normally uses the keywords to match knowledge and help engineers to provide the process knowledge from repository. The system will retrieve the process library automatically. Then the part drawing and

processing knowledge would be generated in a mapping list, and provided the matched knowledge results to the engineers, as shown in Figure 3.

If an engineer receives a task to design surface processing for a part, the detail operation steps are shown as follow:

• Step 1: Enter keywords, the system would analyze and disaggregate the keywords to retrieve from the knowledge repository.
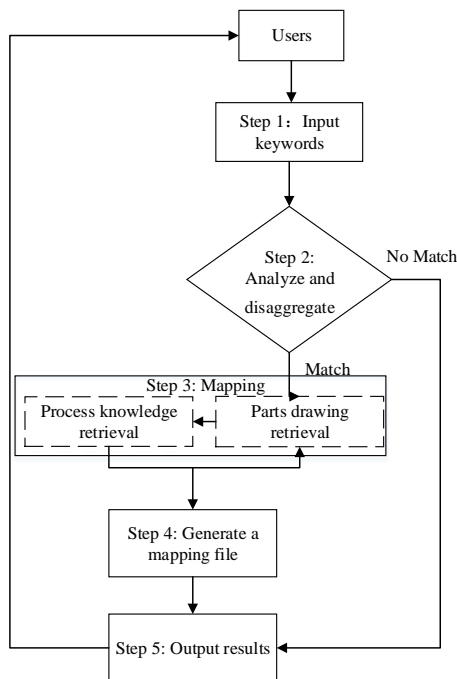
FIGURE 3. The detail process of knowledge retrieval based on keywords.

• Step 2: If there has an existed instance or case of the part containing the keywords in the part library, this part drawing and process knowledge will be retrieved.

• Step 3: If Step2 has been executed, the system will continue to retrieve the process knowledge repository and the machining process corresponding to each part drawing.

• Step 4: Generate a mapping file according to the parts drawing and corresponding processing with a strict matched relationship.

• Step 5: Return the result to engineers.

If Step 2 is not executed, that means no part information related in parts library is available, then there will do not have retrieval results can be returned. Alternatively, the system will return the knowledge result to engineers in the form of a reference list.

B PROCESS KNOWLEDGE RETRIEVAL METHOD BASED ON CUSTOMER ORDERS

Process knowledge retrieval method based on customer orders can help engineers to acquire the customers' orders and the related process knowledge. This method is realized by using the TreeView technology as navigation by storing and displaying the parts knowledge presented as a tree structure. The part type is defined as the navigation node. Through connection with the database, part types can be classified to a hierarchical structure.

TreeView is commonly used to display files, directories and information that needs to be displayed in a hierarchical formation. There are three ways to use TreeView technology in practice: (1) Insert TreeView control panel directly into the ongoing software code; (2) load from the XML file data to establish a tree structure; (3) load or read data from the

database to establish a tree structure. The third way is integrated in this paper, data and information can be read from the database, the client is set as the parent node while the part type is set as a child node. Parts drawings and processing technology would be represented as process knowledge shown to the users in a knowledge list. The advantage of this method is that it can clearly show the different types of knowledge and provide knowledge content promptly. After clicking on the specific classification, one can view the knowledge type to avoid time waste.

This knowledge sharing method realize the mapping between customer orders and the processing knowledge in the tree navigation form. Firstly, analyze the customer names, read all the parts types related to this customer from the database. At the same time, match and map the relationship between the parts database and process database to generate a correlation file. Then the relationship of these objects the will be formed a tree structure to display the knowledge.

C PROCESS KNOWLEDGE RETRIEVAL METHOD BASED ON MANUFACTURING PROCESSES

Process knowledge retrieval method based on manufacturing processes can realize knowledge reuse through analyzing the knowledge of surface processing, design features, heat treatment. Generally, surface processing contains cylindrical surface processing, hole processing and planar machining. Design features consist of rectangular cubes, cylinders, cones, balls, holes, bosses, cavities, keyways, grooves, ribs, threads et al. Heat treatment contains normalizing, annealing, aging, quenching, tempering, tempering, carburizing, nitriding et al.

At first, this method analyze the machining process of a part. Then the analysis results are used to match with the information in the database. With the matched result (part knowledge), the system will automatically access the process knowledge repository to retrieve the related knowledge of the process, then the results would be returned to the engineer at the end step. The knowledge can be shown as three kinds of surface processing: cylindrical surface processing, hole processing and plane processing. There may have different solutions to achieve the processing for a part. In general, the choice of processing options should be able to meet the processing requirements of parts. The exceptions of precision requirements is a low production cost can improve the processing. In this paper, the processing knowledge retrieval can be based on different technologies, considering the economic processing accuracy grade and surface quality requirements, along with selecting the corresponding surface processing program for the preparation of parts processing technology to provide a reference.

V. KNOWLEDGE RECOMMENDATION METHOD BASED ON VECTOR SPACE MODEL

A KNOWLEDGE RECOMMENDATION PROCESS

Knowledge recommendation in this paper means that knowledge resources can be provided timely and matched accurately to engineers in supporting their work according to the interests and design tasks. The recommendation aim is to meet the engineer's knowledge demands that would solve the isolated island problem caused by the knowledge proliferation. For the mechanical parts knowledge, in order to improve the acquisition efficiency, a case set-based knowledge recommendation method has been proposed in this paper. The knowledge recommendation process includes six steps as shown in Figure 4.
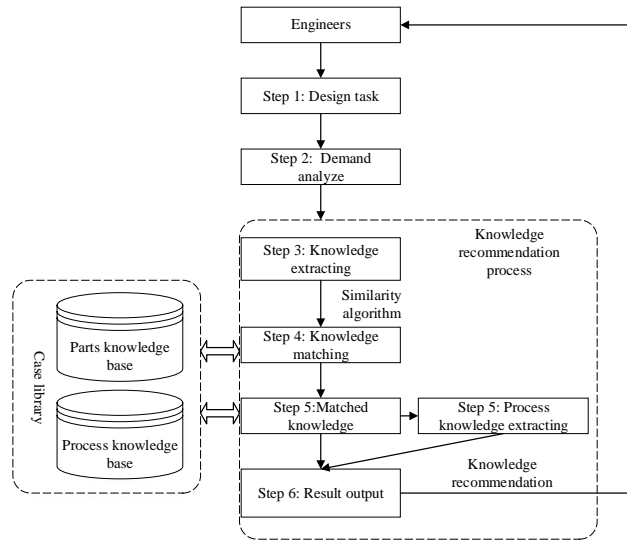

FIGURE 4. Knowledge recommendation process.

• Step 1: Engineers receive the product design task, generate the knowledge demand.

• Step 2: After analyzing the knowledge demand of engineers, the knowledge resource would be extracted from knowledge repository.

• Step 3: Use the similarity algorithm to analyze and match the demand with knowledge resource.

• Step 4: Generate the most similar matching knowledge list to map with process knowledge in the process library.

• Step 5: Link and map the knowledge to generate a mapping relationship.

• Step 6: Output the recommender results listed by descending order of similarity value.

The knowledge recommendation method contains and refines the attributes of the information acquisition through selecting the matched knowledge from repository according to user's demands. It can provide knowledge to engineers actively and timely by ensuring the accuracy of knowledge acquisition, reducing the time cost and greatly improving the efficiency of knowledge acquisition.

B DESIGN OF SIMILARITY MODEL FOR KNOWLEDGE RECOMMENDATION

In this paper, the vector space model is used to represent the '*file*, and $tf \times idf$ denotes the word weight of the

coordinate system. In the '*file*', tf denotes the occurrence frequency of the word '*word*, idf is the frequency number of the inverse '*file*'. The $tf \times idf$ means the vector coordinate of these two factors. The specific model is given as follows:

(1) First, calculate the knowledge recoed frequency in a '*file*'.

$$TF_{(i,j)} = \begin{bmatrix} tf_{(1,1)} & tf_{(1,2)} & \cdots & tf_{(1,j)} \\ tf_{(2,1)} & tf_{(2,2)} & \cdots & tf_{(2,j)} \\ \vdots & \vdots & \ddots & \vdots \\ tf_{(i,1)} & tf_{(i,2)} & \cdots & tf_{(i,j)} \end{bmatrix} \quad (1)$$

Where $tf_{(i,j)}$ denotes the *j-th* knowledge frequency which is existed in *i-th* '*file*'.

(2) Reverse '*file*' frequency can be defined as:

$$IDF_j = \log(N/N_j) = [idf_1, idf_2, \cdots, idf_j] \quad (2)$$

Where N denotes the quantity of files, N_j denotes the quentity of files have the *j-th* resource, idf_j is the *j-th* reverse '*file*' frequency.

(3) The weight can be defined as:

$$TW_{(i,j)} = \begin{bmatrix} tf_{(1,1)} \times idf_1 & tf_{(1,2)} \times idf_2 & \cdots & tf_{(1,j)} \times idf_j \\ tf_{(2,1)} \times idf_1 & tf_{(2,2)} \times idf_2 & \cdots & tf_{(2,j)} \times idf_j \\ \vdots & \vdots & \ddots & \vdots \\ tf_{(i,1)} \times idf_1 & tf_{(i,2)} \times idf_2 & \cdots & tf_{(i,j)} \times idf_j \end{bmatrix}$$
$$= \begin{bmatrix} tw_{(1,1)} & tw_{(1,2)} & \cdots & tw_{(1,j)} \\ tw_{(2,1)} & tw_{(2,2)} & \cdots & tw_{(2,j)} \\ \vdots & \vdots & \ddots & \vdots \\ tw_{(i,1)} & tw_{(i,2)} & \cdots & tw_{(i,j)} \end{bmatrix} \quad (3)$$

Where $tw_{(i,j)}$ denotes the weight of the *j-th* resource in the *i* '*file*'.

(4) The weight of current matched resource:
$$QW_j = [qw_1, qw_2, \cdots, qw_j]$$
$$= \begin{cases} tf_j \times idf_j & Mapping\ knowledge \subseteq knowledge \\ 0 & other \end{cases} \quad (4)$$

Where tf_j denotes the stored frequency of the *j-th* knowledge.

(5) The similarity is the weighted weight of the document that contains the current knowledge, that is:

$$S_i = \sum TW_{(i,j)} QW_j^T \quad (5)$$

From the description above, the knowledge service system would recommend knowledge to engineers according to similarity value list by descending order.

This model can show that the weight is derived from the calculation of the system, thus it overcomes the weight of the configuration depends on the subjective judgment and experience of the designer and can achieve the non-human interference associated knowledge recommendation.

VI. APPLICATION SCENARIOS AND EVALUATION OF THE PROPOSED METHOD IN A PRODUCT DEVELOPMENT PROJECT

A. SYSTEM ARCHITECTURE OF KNOWLEDGE RECOMMENDATION METHOD

Figure 5 provides the system architecture for the proposed knowledge recommendation method, which consists of four layers.

The user layer contains internal and external portals for different users. The application layer includes the operational system for the organizations. The service layer is defined to realize the key technologies mainly including knowledge representaton, knowledge sharing and knowledge recommender. The representation layer is the knowedge representation method and technologies to realize the knowledge service. Knowledge resource layer generally consist of knowledge stored in different mediums and different information systems. This system is based on the J2EE architecture, which is design to realize and meet the technical requirements.
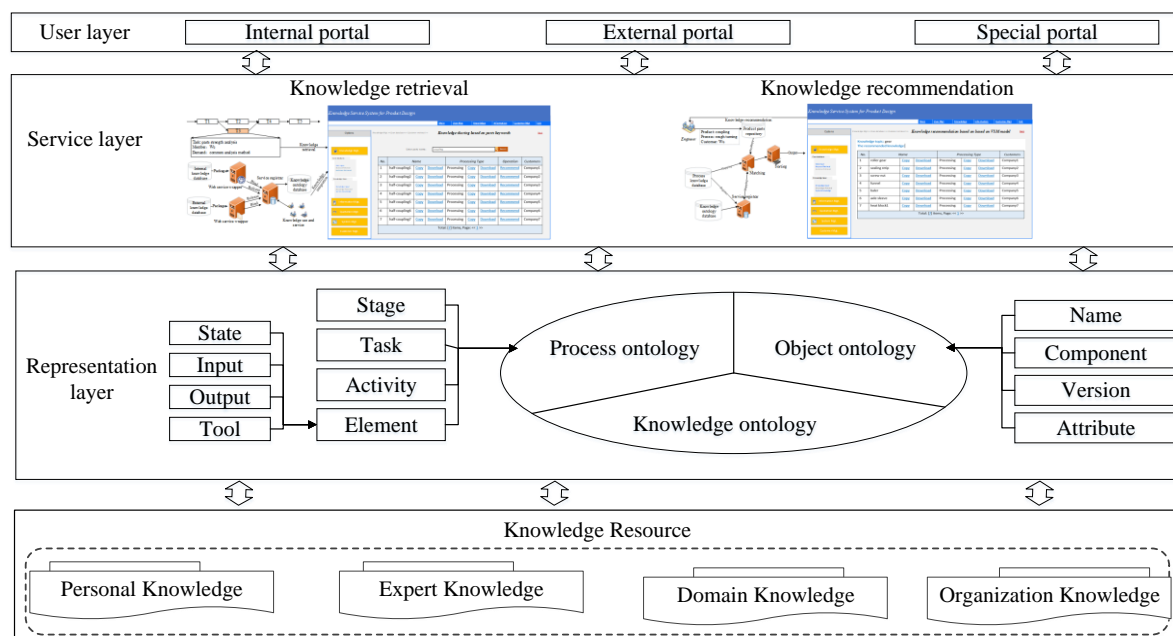

FIGURE 5. System architecture for knowledge recommendation service system.

B APPLICATION SCENARIOS OF THE PROPOSED METHOD

A knowledge recommendation system is developed to demonstrate the framework and method proposed in this paper. This system is developed on MVC mode of J2EE, MySQL as the database, MyEclipse software as a development tool. This system consists of resource management, data management, application collaboration and device-independent presentation layer, and can help to realize the parts knowledge sharing, acquirement, reuse and innovation for product development.

As mentioned above, four application scenarios are provided to demonstrate knowledge sharing and recommendation shown as follow:
- Knowledge sharing based on parts keywords
- Knowledge sharing based on customer orders
- Knowledge sharing based on manufacturing processes
- Knowledge recommendation based on vector space model

(1) The demonstration of parts keyword-based knowledge acquisition. This method realizes the knowledge mapping of "parts drawing–processing knowledge". It can help engineers for their instant knowledge requires. This method only requires the user to enter the keywords, and the related knowledge would be shown. The application scenario is demonstrated in Figure 6.

(2) The demonstration customer order-based knowledge acquisition. This method builds the mapping relationship from customer information to knowledge. When an engineer receives a task, and this task belong to a project which is related to a customer. They are able to retrieve all parts knowledge and process knowledge related to this customer. Then engineers can consider some particularity for this customer in product development. This method uses tree navigation to show the knowledge structural classification. Clicking on the specific classification, engineers can obtain the relevant knowledge. For example, after entering keywords in the text box, on the left side of the system screen will output the match results formed as tree navigation. At the right part of the system screen, there would show querying all parts knowledge and process knowledge related to this customer. The application scenario is demonstrated in Figure 7.
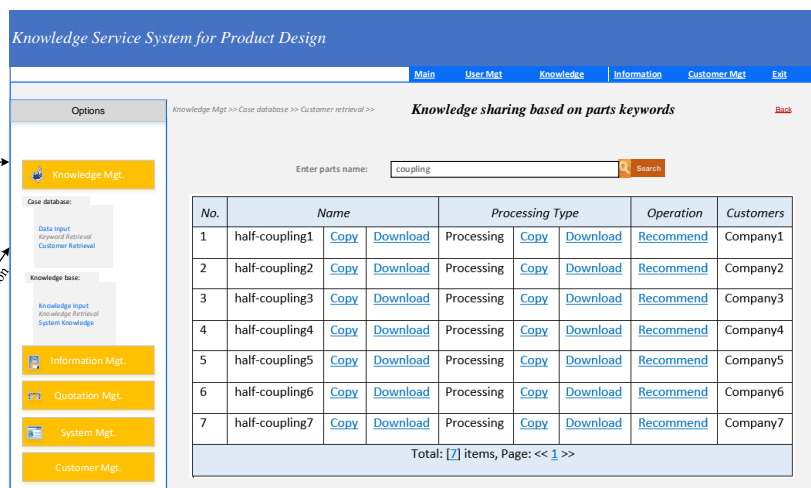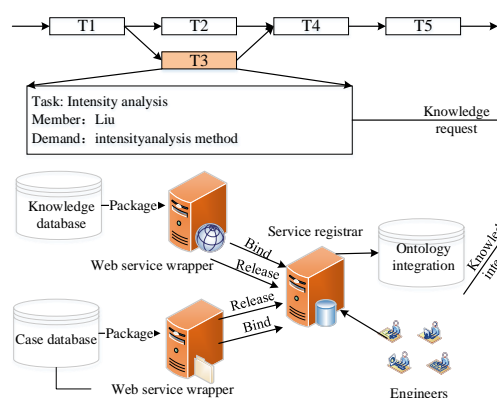
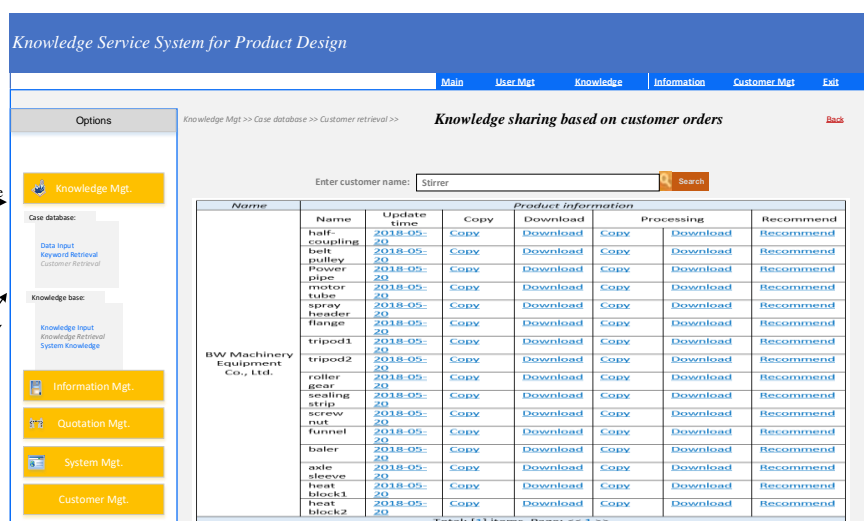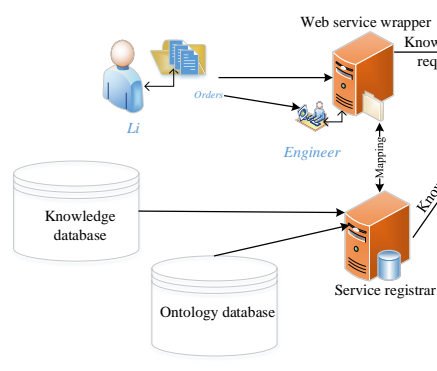**FIGURE 6. The demonstration of parts keyword-based knowledge acquisition.**

FIGURE 7. The demonstration customer order-based knowledge acquisition.
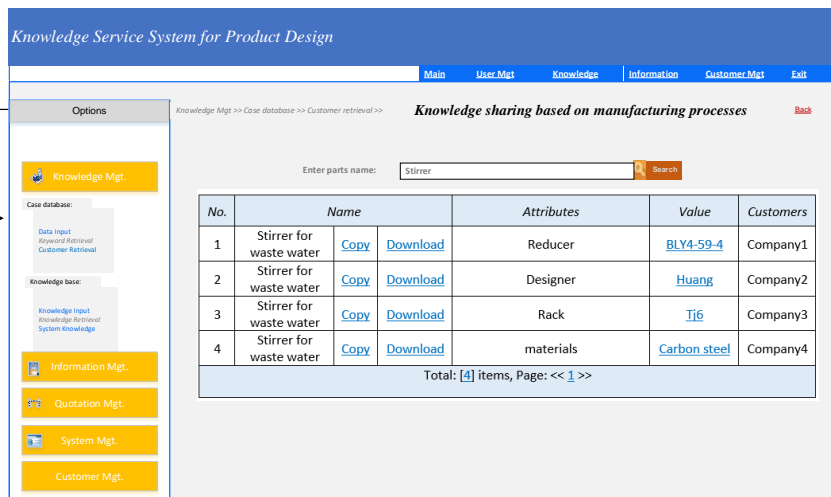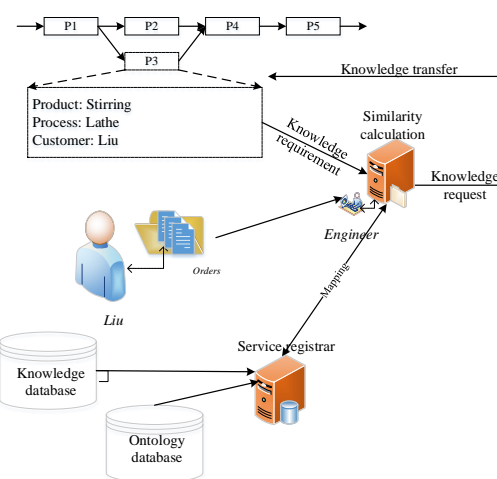

FIGURE 8. The demonstration process-based knowledge acquisition.

(3) The demonstration process-based knowledge acquisition. This method realizes the mapping of 'parts drawing-knowledge'. The system retrieves knowledge resource database according to retrieval content and presents the related part drawing and processing knowledge to generate a mapping between drawing and processing knowledge. Actually, if the processing knowledge includes the outer surface processing, the hole processing or the plane machining, the system will retrieve the related knowledge according to the outer surface processing, hole processing or plane processing. These surface processing programs can be exported as an Excel format file to facilitate the knowledge

sharing and reuse. The application scenario is demonstrated in Figure 8.

(4) The demonstration for knowledge recommendation based on vector space model. The proposed method is an effective way to improve the knowledge acquisition efficiency in the part development and manufacturing. The system will match the part knowledge related to the current knowledge requirement of the engineers from the knowledge library according to their current task. Then after the similarity calculation, the matched knowledge will be provided to the engineers. The application scenario is demonstrated in Figure 9.
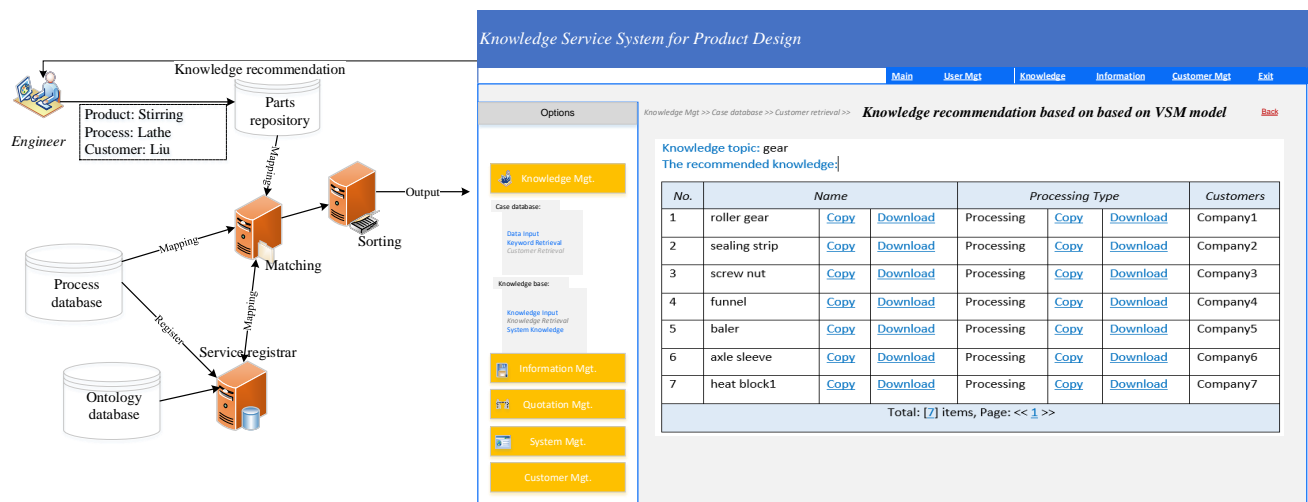

FIGURE 9. The demonstration vector space model-based knowledge recommendation.

TABLE I
BENEFITS OF PROPOSED APPROACH.

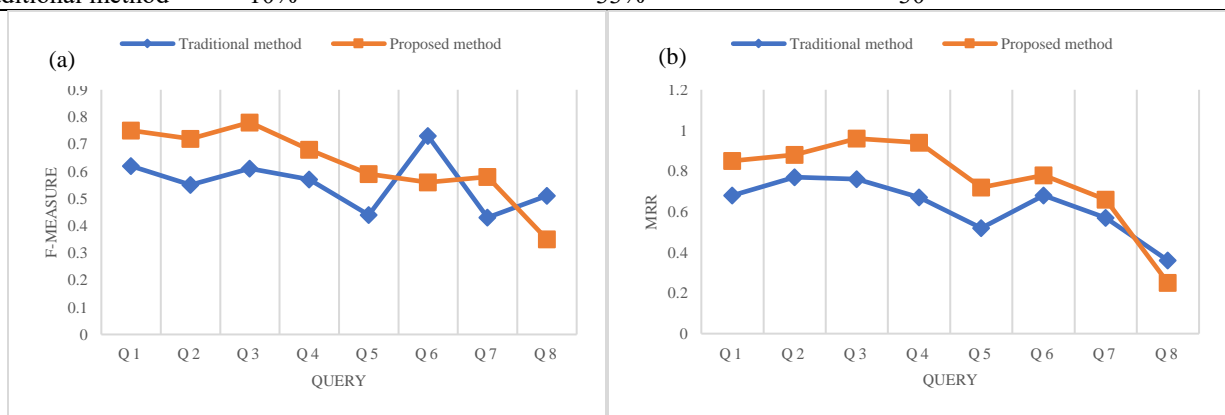|	Knowledge browsing time	Knowledge utilization	Frequency of design change
Proposed method	5%	55%	17
Traditional method	10%	33%	30

FIGURE 10. (a) F-score and (b) MRR experimental results.

C. EXPERIMENTAL EVALUATION

1) TECHNICAL BENEFITS
In order to show the technical benefits of the proposed method, the proposed knowledge recommendation process compare with the knowledge retrieval process generally used

as usual. A survey of a new product development was conducted. From this survey, it can be observed from the Table I that the knowledge browsing time reduces from 10% to 5%. Comparing with the traditional method, the knowledge utilization of the proposed method rises from 33% to 55%. It also can be seem that the frequency of design change reduces to 17% from 30%.

2) PERFORMANCE EVALUATION

For the empirical evaluation of the proposed method, the famous F-measure method is used to measure the performance, which includes two metrics, namely, precision (p) and recall (r). Assume β is the relative importance of each measure. Then it can be defined as:

$$F_\beta = (1 + \beta^2)\frac{p \cdot r}{(\beta^2 \cdot p) + r}$$

$$p = \frac{|\{relevant\ documents\} \cap \{retrieved\ documents\}|}{|\{retrieved\ documents\}|}, \text{ and}$$

$$r = \frac{|\{relevant\ documents\} \cap \{retrieved\ documents\}|}{|\{relevant\ documents\}|}.$$

The mean reciprocal rank (MRR) generally is used to evaluate the effectiveness a result list which response to a query, ordered by probability of correctness. The MRR can also be used to measure the results of knowledge recommendation. The formula of *MRR* is:

$$MRR = \frac{\sum_{i=1}^{n}\left(\frac{1}{i} \times R_i\right)}{\sum_{i=1}^{n}\frac{1}{i}}$$

Where n denotes the quantity of response results, $R_i = 1$ if the result is relevant, and $R_i = 0$ otherwise.

There are three teams involved in this experiment including product development engineers, process control team, and administration team. The data source for the experiment collect from these three teams. The dataset for each engineer and team member include knowledge requirement and the record of knowledge browsing from the system over 66 workdays. During the experiment span, the engineers, the process control team and the administration team work together for a new product development project. Each participant would be generated a record including the knowledge requirement and the knowledge browsing frequency.

As shown in Figure 10, it provides the F-score result and the MRR result based on the experiments. From the results, it can be seen that the proposed method is better, as it is attributed independently.

VII. CONCLUSION AND FUTURE PERSPECTIVE

This paper proposes a vector space model-based method to enhance the ability of knowledge acquirement during product development. To address the efficiency of knowledge acquirement, the similarity matching algorithm is used to validate the proposed knowledge recommendation method. The demonstration of the knowledge recommendation system show the benefits of the implementation of the proposed method.

The conclusion can be summarized as follows:

- A case set-based knowledge service framework is proposed to meet the knowledge requirement during product development. This framework can integrate with mechanical product development processes.
- A vetor space model-based knowledge recommender method is proposed by using similarity matching algorithm to support engineers acquire knowledge more efficient.

- A knowledge service system is provided to illustrate the application effect of knowledge acquirement. To compare the benefit of proposed method with the traditional knowledge acquirement method, an experimental evaluation is designed and it shows that the proposed method is better than the traditional method.

In the future, the next step of this study can focus on the topics as follows:

- More practices related to this study can be conducted furtherly to extend the proposed method.
- The proposed knowledge service system can use new information technologies furtherly including social media, artificial intelligence and machine learning.

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