Product Innovation Design Process Model Based on Knowledge Service

Kai Zhang, Xin Guo, Miao Yu*, Ling Chen
1. School of Mechanical Engineering, Sichuan University, Chengdu 610065
2. Innovation Method and Creative Design Key Laboratory of Sichuan Province, Chengdu 610065, China)
E-mail: miaoyu@scu.edu.cn

Abstract. With the advent of the era of knowledge economy, knowledge plays an increasingly important role in product innovation design. In order to help designers to acquire and apply knowledge in product innovation design process, a kind of model of product innovation design process based on knowledge service was proposed. Product innovation design was divided into several stages: requirement analysis, problem determination, problem solving and solution evaluating. And the mapping relationship between design process, service strategy and service knowledge was also analysed. Taking the designers as the main body of knowledge service, a knowledge service strategy supporting design process was proposed. In view of the different knowledge services required in different stages of product innovation design process, the forms and service strategies of knowledge in various stages of product design were studied step by step, and the product innovation design service composition model that conforms to the designer's habits of mind was put forward. This method links the knowledge and design process in each stage of product innovation design process with the combination of innovation strategy and design knowledge, which is used to assist designers in tracking and applying the required knowledge resources for innovation design. Finally, a prototype system of product innovation design knowledge service was developed, and a design case of micro force measuring device was presented to demonstrate the practicability and validity of the proposed method.

1. Introduction
Innovative design is the essence of product design, which is based on knowledge [1]. With the advent of the era of knowledge economy, the knowledge of product design is growing explosively. Designers need multidisciplinary knowledge to support product design [2]. It is an urgent problem for knowledge management to deal with the overflow of knowledge and obtain effective knowledge from a large number of knowledge resources to assist product innovation design [3].

As an integrated carrier of design resources, knowledge service can provide designers with corresponding innovation strategies, design methods, knowledge and other resources to assist designers in their innovative designs. Extensive theoretical research has been carried out, mainly in the aspects of knowledge integration, knowledge push, service architecture, etc. Through modeling the knowledge flow and knowledge sharing in the design process, Liu proposed a method of knowledge sharing, reuse and integration in the design evaluation of mechanical system based on Web services to assist designers to make full use of multidisciplinary design knowledge [4]. To accelerate the customization innovation service design, Lee proposed a knowledge-based service design model by integrating case-based reasoning and TRIZ [5]. Wan and his coworkers applied QFD, material field model, conflict matrix,
morphological analysis method and other methods to problem analysis and concept solution, and proposed a multi method integrated product innovation strategy and design process [6]. By analyzing the hierarchical relationship among design tasks, designers, design activities and design knowledge, Zhang established the mapping relationship between product innovation design process and required knowledge, and established a knowledge push model of product innovation design based on QFKD [7]. Wang and Yang proposed a service-oriented architecture service cognitive composition model for innovative design from the perspective of knowledge dimension, strategy dimension and computer tool dimension [8, 9]. In addition, a large number of scholars have put forward the service mechanism of knowledge support product innovation design from the aspects of product service system, supply chain, network collaboration [10-12].

Previous research have improved the efficiency of knowledge service to a certain extent. However, little attention has been paid to the designer’s problem-solving thinking process and problem-solving law. There is no universal knowledge to support product innovation design mode. In this article, designers are regarded as the main body of knowledge services, and different kinds of product innovation design issues are considered. The product innovation design process model based on knowledge services is established through a service model that combines innovation strategy and design knowledge to systematically assist designers in product innovation design.

2. Product innovation knowledge service strategy supporting the design process

The product innovation design process is the thinking process in which the designer obtains design information from the outside, invokes and extracts design knowledge, and then outputs the solution after comprehensive processing, that is, the thinking process of creatively solving the acquired problems [6]. In order to assist designers to use knowledge reasonably in product innovation design, a product innovation knowledge service strategy supporting the design process were established in this article, as shown in Figure 1.

![Figure 1. Product innovation knowledge service strategy supporting design process](image_url)

(1) The design process. Design process represents the tasks that designers need to complete in the process of product innovation design, including requirement analysis, problem determination, problem solving and scheme evaluation.

(2) Service knowledge. At different stages in the process of product innovation and design, the knowledge requirement of designers are differentiated.

(3) Service strategy. Service strategy is to use knowledge to induce the creative thinking of designers in the process of product innovation and design. The problem-solving process is not just the invoking
of knowledge. A knowledge service strategy that conforms to the thinking habits of designers can assist the designer in solving problems better.

3. Service composition model of product innovation design process

Based on the in-depth analysis of the design process and service strategy, the product innovation design service combination model that conforms to the thinking habits of designer is proposed in this article to assist the designer in solving the problem creatively, as shown in Figure 2.

![Figure 2. Product innovation design process service composition model](image)

3.1 Knowledge service supporting requirement analysis

The requirement analysis knowledge service is mainly used to assist the designer to determine user requirements according to the design task. There is four ways to obtain user requirements: market research, quality information, design experience and experts predict. After the acquired requirements are standardized and expressed, the importance of requirements can be determined, and the direction of product innovation design can be determined accordingly.

3.2 Knowledge service to support problem determination

Problem determination knowledge services are mainly used to assist designers in determining product design problems based on user requirements. 1) From the perspective of product performance, the Quality Function Deployment (QFD) theory is adopted to transform the user requirements acquired in the previous stage, convert user requirements into product performance. 2) From the perspective of requirement contradiction, the TRIZ theory and the Ideal Final Result (IFR) method are used to find out the crux of the product design problem and finally determine the problem. Through this method, three
types of innovative design problems can be obtained: functional problems, combination problems and heuristic problems.

3.3 Knowledge service to support problem solving
Product design issues involve multiple aspects such as existing product improvement, new product development, simple structure design, and complex system integration. Combined with the problem types determined in the previous stage, the strategies of guided incentive solution, combined incentive solution, and inspired incentive solution are used to guide the innovative thinking of designers.

3.3.1 Guide incentive strategy
The guidance and incentive strategy is suitable for product innovation design with functional problems. Guide incentive strategy mainly include TRIZ service strategy, Function Behavior Structure (FBS) service strategy, Creativity Templates (CT) service strategy, which can assist designers in invoking functional knowledge services, structural knowledge services, scientific effects knowledge services, and invention principles knowledge services.

3.3.2 Combination incentive strategy
Combination incentive strategy is suitable for the innovative design of products or systems that do not have a clear physical structure to achieve a specific goal. Analogy service strategy, combined service strategy, checklist service strategy are the main methods suitable for combined incentive strategy.

3.3.3 Heuristic incentive strategy
The heuristic incentive strategy is suitable for the design problems without specific goals, that is, the product innovation design with non-logical thinking. The strategy will push a lot of knowledge related to or unrelated to the design problem (including pictures, text, video, animation), which can lead to creativity. The suitable inspiration strategies include brainstorming service strategy, mind map service strategy and knowledge traversal service strategy.

3.4 Knowledge services supporting scheme evaluation
After solving the problem, multiple innovative solutions are obtained. Therefore, it is necessary to optimize and evaluate the innovative solution. There are two main service strategies for scheme evaluation: 1) For the design problems with clear design goals and user requirements, a service strategy combining QFD and Analytic Hierarchy Process (AHP) is used. 2) For the design question has no clear goals or design user requirements, with the support of multi-domain knowledge services, qualitatively evaluate the solutions in terms of product safety, innovation, economy, and product performance.

4. Application example
Based on the Java platform, in the Java eclipse development environment, SQL server is used as the storage and management database of design knowledge, the product innovation knowledge service prototype system supporting the design process is developed by the method described in this article. In order to demonstrate the product innovation design knowledge service method and the function of the prototype system described in this article, the design process of the micro-force measuring device is taken as an example.

The micro-force measuring device plays an important role in the field of precision mechanical design and measurement, which is an important equipment for research from macro to micro. The problems of low measurement accuracy, unstable thrust and speed, irregular target path, tedious manual calculation, and high-requirement target shape are the main problems existing in the existing traditional micro-force measuring devices. Therefore, it is necessary to develop a new type of micro-force measuring device.

Through an in-depth analysis of the design tasks, the designer standardized the user requirements and organized them into 10 items, as shown in Table 1.
Table 1 User requirements for micro force measuring device

| Number | Requirement content                  | Number | Requirement content                  |
|--------|--------------------------------------|--------|--------------------------------------|
| 1      | High measurement accuracy            | 6      | Low environmental requirements       |
| 2      | Stable thrust, adjustable            | 7      | Easy to maintain                     |
| 3      | Stable speed, adjustable             | 8      | durable                              |
| 4      | Path specification                   | 9      | Simple structure                     |
| 5      | Convenient operation and high efficiency | 10     | Low price                            |

The QFD theory is used to analyze and process the performance of the micro-force measuring device. Through obtaining the corresponding product features, the quality house constructed is shown in Figure 3. Through the evaluation and analysis of the House of Quality (HoQ), the functional characteristics of the micro-force measuring device that need to be improved urgently are the propulsion device, structural layout, component shape, adaptability and automatic control ability, and the technical conflicts between “propulsion device and image acquisition”, “structure layout and automatic control”.

Figure 3. The HoQ of micro force measuring device

In addition, the contradiction of user requirements is analyzed through the IFR method (as shown in Figure 4). It is found that user hopes to obtain pictures with fast speed and clear quality. At the same time, during the process of obtaining pictures, the speed and tension of the pushing device are constant. However, the increase of the advancing speed will cause the unevenness of the sharpness of the captured
pictures, which will have a certain impact on the fitting and the final measurement results, which will cause the measurement accuracy to decrease.

Figure 4. The requirement contradiction of micro force measuring device

After determining the design problem, the service strategy is used to push the knowledge to solve the problem. It can be obtained that: (1) “friction effect”, “adsorption effect”, “spring effect”, “surface roughness” and other effect knowledge; (2) “Super-hydrophobic surface”, “actuator”, “optical sensing”, “self-cleaning”, “interfacial tension”, “new materials” and other domain knowledge; (3) “with the help of intermediary”, “reverse action”, “dynamic characteristics” and “mechanical system replacement” and other principle knowledge. According to the results of the knowledge push, combined with the micro-force measuring device system itself and specific design issues, a preliminary idea about the design of the micro-force measuring system can be obtained.

The main reason that affects the measurement accuracy of the micro-force measurement device is the image acquisition. The image acquisition system directly affects the image fitting and calculation of the micro-force. The fundamental reason that affects the weight of the micro-force measurement device is the driving device and material. The driving forms include motor drive, hydraulic pressure drive and memory alloy drive. Based on the working environment requirements of the micro-force measuring device system, a small-sized and large-output motor is selected to drive. Considering the adhesion of super-hydrophobic surfaces, the material is generally aluminum. It is the transmission method and base material that affect the speed and tensile stability of the micro-force measuring device. The PLC-controlled linear stepping motor is selected as the drive and the self-made super-hydrophobic surface can ensure the stable transmission speed and tensile force. The main influence on the automatic control ability of the micro-force measuring device is the travel path and correction method of the target. The
initial selection is to fix the travel path of the target (processing special-shaped grooves). Deviation in the groove. Super-hydrophobic surface are chosen as the surrounding surface to prevent the droplets from deviating in the groove.

Through further analysis, it is found that with the development of microscopic technology, the measurement accuracy of traditional manual operation or force balance measuring devices using tiny weights remains at the Newton level, which can no longer meet the accuracy requirements. Using industrial cameras instead of weights for manual measurement and calculation can improve the measurement accuracy to a certain extent. However, if the measurement efficiency is to be improved, the advancing speed of the stepping motor needs to be accelerated, which will cause the distortion of the captured image and the decrease of measurement accuracy. That is, there is a technical conflict between “propulsion device and image acquisition”, which is defined as technical conflict 1. In addition, the structure of the micro-force measuring device is too simple, which will result in poor automatic control capabilities and insufficient adjustability. That is, there is a technical conflict between “structure layout and automatic control”, which is defined as technical conflict 2. According to TRIZ theory [13], there are two technical conflicts in technical conflict 1. The improvement parameter in technical conflict 1 (a) is the measurement accuracy (the limit of the available force of the device), and the worse parameter is the speed (the speed of the propulsion device is reduced). The improved parameter in technical conflict 1(b) is the harmful factor produced by the object (the friction generated during the propulsion process), and the worse parameter is the weight of the moving object (the mass of the measured object is reduced). In technical conflict 2, the improvement parameter is the complexity of the system (simple device), and the deterioration parameter is the degree of automation (insufficient automatic control capability). The principle of invention is an effective method to resolve technical conflicts. Designers can select appropriate invention principles based on the results of knowledge push to resolve technical conflicts and complete design tasks.

![Figure 5. The image acquisition definition adjustment of micro force measuring device](image-url)
Among them, “with the aid of intermediaries” and “mechanical system replacement” are helpful to resolve conflict 1(a) and technical conflict 2. A fixed ultra-thin elastic sheet with a known elastic coefficient is considered to be added on the device. The droplet is placed between the elastic sheet and the target. When the propelling device pushes the target, the droplet can be regarded as a spring, and the elastic sheet is also affected when the target is stretched. Since the elasticity of the elastic sheet is known and the position is fixed, the resulting shape change is easy to measure. Thus, the influence of the uneven deformation of the droplet caused by the excessive speed on the calculation can be eliminated. Furthermore, in order to capture the image target and the liquid separation moment better, the optical system can be introduced: A high-speed camera is added directly above the active area. The high-speed camera can obtain more picture frames per second, which can better record the state of the separation moment, and reduce the impact of speed on picture quality. The controller can also be used to adjust the propeller to advance at a variable speed, that is, the speed is faster in the unseparated stage, and the speed is reduced in the separation stage, and finally the separation state picture is clear and stable. According to the obtained “optical sensing”, “new material” and other field knowledge, the introduction of optical components (high-speed camera) instead of the original manual (mobile phone shooting) to capture the separation situation. The new long-acting superhydrophobic surface with micro-scale structure replaces the original self-made superhydrophobic surface, as shown in Figure 5.

![Figure 6. The friction adjustment of micro force measuring device](image)

The linear stepping motor controlled by PLC is used to replace the original spiral micrometer to control the speed and tension. Without increasing the system complexity of the micro-force measuring device, the problem of automatically controlling the propulsion of the target is solved, and the degree of automation is improved. The principle of “dynamic characteristics” is helpful for technical conflict 1(b) and technical conflict 2. The presence of friction will reduce the accuracy of the measurement. Therefore, a filament connecting the solid top plate and the target is added on the device. The filament allows the
object to be suspended, and its position keeps its center on the same horizontal line as the center of the droplet, as shown in Figure 6. When the bottom plate and the top plate move under the action of the propulsion device, the suspended target can also maintain a force balance state and advance until it separates from the droplet. After the target is suspended from the surface, there will be no friction when it is stretched laterally. Therefore, without increasing the complexity of the system device, the purpose of controlling the harmful effects of the target is achieved.

![Figure 7 Design scheme of micro force measuring device](image)

Furthermore, product safety, innovation, economy and other aspects must be considered to supplement and optimize the device. In the scheme evaluation process of the micro-force measuring device, the designer should consider the fusion and integration of the control system, the mechanical system and the detection system to obtain the final innovative design plan, as shown in Figure 7.

The micro-force measuring device has a simple structure and a reasonable design. It also realizes multiple functional controls such as stretching speed, stretching force, image quality, path specification, etc., and is relatively convenient to operate and maintain, and work is stable and reliable.

5. **Conclusions**

The product innovation design knowledge service technology that supports the design process is proposed in this article. Based on the design subject of the designer, combined with the different knowledge required at different stages of product innovation and design, a knowledge service method that conforms to the thinking habits of designer is proposed to support the design decision. The specific problems in the product innovation design process are systematically analyzed: With the designer as the core, the mapping and integration of service strategies and knowledge resources are studied from the four stages of requirement analysis, problem determination, problem solving, and scheme evaluation, which improves the knowledge service efficiency and accuracy, and realized knowledge to support product innovation design. The problem-solving strategy described in this article provides the theoretical guidance for designers to carry out product innovation design.

**Acknowledgments**

This work has been supported by the Science & Technology Ministry Innovation Method Program, China (No. 2020IM020400), the Sichuan Major Science and Technology Project, China (No. 2019YFG0397), and the Sichuan Province Science Technology Support Program (No.2019YFG0373).
References

[1] T. J. Howard, S. J. Culley, E. Dekoninck. Describing the creative design process by the integration of engineering design and cognitive psychology literature[J]. *Design Studies, 2008*, 29(2):160-180.

[2] Yan X. Q., Li Y., Chen J., et al. A method of implementing formalized multidisciplinary collaboration in product conceptual design process[J]. *PI Mech Eng C-J Mec, 2017*, 231(18): 3342-3357.

[3] Qin H., Wang H. W., Aylmer L. Johnson. A RFBSE model for capturing engineers’ useful knowledge and experience during the design process[J]. *Robot Cim-Int Manuf, 2017* (44):30-43.

[4] Liu J., Zhang Z. N., Richard E. Web services-based knowledge sharing, reuse and integration in the design evaluation of mechanical systems[J]. *Robot Cim-Int Manuf, 2019* (57) :271–281.

[5] Lee C. H., Chen C. H., Li F., et al. Customized and knowledge-centric service design model integrating case-based reasoning and TRIZ[J]. *Expert Syst Appl, 2020* (143): 113062.

[6] Wan Y. J., Li Y., Li W. Q., et al. Strategy and realization for integrated product innovation design based on cognitive multi-method[J]. *Computer Integrated Manufacturing Systems, 2014*,20(6):1267-1275.

[7] Zhang K., Zhao W., Wang J., et al. Knowledge push technology based on quality function knowledge deployment[J]. *PI Mech Eng C-J Mec, 2019*, 233(4): 1119-1138.

[8] Wang C., Zhao W., Wang J., Chen L. Approach for Process Innovative Design Based on SOA[J]. *Journal of Sichuan University (Engineering Science Edition), 2016*, 48(4):188-196.

[9] Yang K., Li W. Q., Li Y., et al. Product innovative design service cognitive composition model based on SOA[J]. *Computer Integrated Manufacturing Systems, 2014*,20(10):2329-2339.

[10] Mohamed A. B., Rehab M., Mohamed E.. A novel framework to evaluate innovation value proposition for smart product–service systems[J]. *Environ Technol Inno, 2020* (20) :101036.

[11] Peng H., Shen N., Liao H. L. Multiple network embedding, green knowledge integration and green supply chain performance——Investigation based on agglomeration scenario[J]. *J Clean Prod, 2020* (259) :120821.

[12] Zhou X. J., Ming X. G., Chen Z. H., et al. Reference framework for collaborative design and manufacturing based on model, data, and knowledge[J]. *Computer Integrated Manufacturing Systems, 2019*,25(12):3116-3126.

[13] Li Y., Li W. Q. Method to creative design[M]. China, Beijing: Science Press, 2013.