Product Innovation Based on Technology Recombination

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Abstract. Technology recombination is an effective method for product innovation. Through recombination of product technology systems, designers can take advantages of potential technologies to improve quality of a product. This paper proposes technology recombination based on the product innovative design process. A target product is analyzed to identify its technology system as a starting prototype. Two paths are proposed to search for potential technology opportunities based on the product technology and function analysis for the definition of design objectives. Potential alternative technologies are searched for the recombination with technologies used in the existing product prototype. Then operation rules of the product technology recombination are proposed for the new scheme. The entire process is designed to inherit fully advantages of both existing product and potential technology. Feasibility of the proposed method is verified in the technology recombination design of an automatic quantitative CMMs dispensing machine.

Keywords: Technology recombination, Product innovation, Product technology analysis, Operations rules
DOI: https://doi.org/10.14733/cadaps.2022.375-386

1 INTRODUCTION

Product innovation activities are required for enterprises to develop competitive advantages in response to rapid changes of the market [7]. Technology is the key element of product development for support to realize product functions [5]. Inventions are often described as a combination of existing and new technologies. The novelty arises from the recombination and synthesis of existing technologies [3] to meet customer and market needs, which is often characterized by notable advances and high quality of the product [6]. Product innovation can be conducted in recombination of technical elements of the product, such recombination is considered as a main source of technology development in innovation activities [29].

The recombination process breaks the fixed collocation of the original technology system, new elements are introduced to reform the relationship between elements and create the design novelty [3]. Technology recombination is typically manifested through the introduction of new technological functionalities into a set of existing technologies [16]. Searching for potential technologies is a necessary process in the recombination of technologies.

This paper proposes a product innovative process based on technology recombination. The product technology system is analyzed by building an analysis diagram of existing products. Two paths driven by the problem and new requirement are proposed for the technological innovation opportunity discovery. Potential alternative technologies and new technologies are sought for recombination with existing technologies of the product prototype. Innovative design of an automatic quantitative Chinese medicinal materials (CMMs) dispensing machine verifies the proposed method.

2 RELATED WORK

Existing research on technology recombination is mainly from two aspects, key factors of technology recombination and the process of technology recombination. The former analyzes a large number of data sets such as patent bases [9, 11, 14, 25] in technology life cycle, technology readiness level, R&D timespan and budget [11, 12, 13, 22]. For example, an inverted U-shaped relationship was formed for the technological distance and innovation performance [19, 32].

For a realization process of technology recombination, many studies have been conducted. Park and Yoon [21] proposed an approach to determine technology opportunities by applying collaborative technology combinations. Yoon et al [27] suggested ontological functional modeling and representation methods to support reusability of technology, and provided a procedure to identify core functions from patents for technological reusability. Feng et al [10] proposed a framework to explore potential technology convergence relationships in the field. Fai [9] proposed a path for technology convergence between specific industries. Song et al [24] created a network index to evaluate promising technology convergence in several domains. Network analysis methods were used in the patent analysis for technology recombination [14, 15, 17]. Although the existing methods have made progress in technology recombination, there is a lack of paths to find key technologies in the recombination. Traditional methods, such as forecasting by the new value profile [30] and patent-based analysis [16], can obtain some potential technologies, but they are not mature in detailed solutions of problems for technological recombination.

The existing theoretic solutions have made achievements in guidance of technology recombination. However, there is a lack of systematic methods for engineers to follow in product innovation. This paper proposes a systematic approach to generate innovative design schemes driven by technology recombination.

3 PROPOSED METHOD

3.1 Product Technology Analysis

Technology provides a means to achieve the design intent [2] through product functions [28]. Effective identification and analysis of existing technologies of products are the basis of technology-based innovations. Following two processes can be applied.

1)The function analysis: Systems engineering represents an important method in modern technical product development, the breakdown of functions can help designers understand the functional levels and connections among functions. Relationship of product functions can then be built based on the function decomposition and flow analysis as shown in Figure 1 [26].

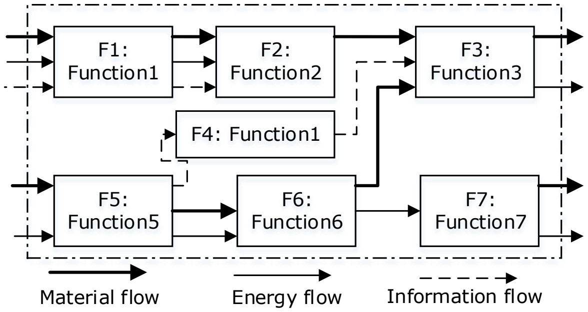


Figure 1: Function structure model.

2) Product technology analysis: A product technology system consists of sub-technologies related to power, transmission, execution and control, which can be sorted according to their importance. Therefore, a product technology system can be expressed as T = (T1, T2, ···, Ti, Ti+1···) with the importance of Ti>Ti+1. A set of functions formed by technologies can be decided by analyzing the product function model, in which functions with the greatest impact on the product system are core functions of the product. The principle and carrier of each core function can be decided as shown in Figure 2.

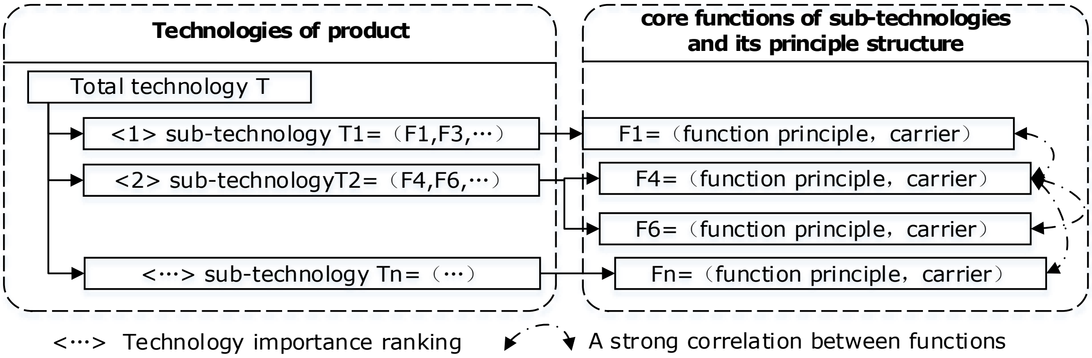


Figure 2: Product technology analysis.

3.2 Production Innovation based on Technology Recombination

Technology recombination is a process of discovering potential technologies and combining them into the existing product technology system. The process integrates advantages of technologies in four stages as shown in Figure 3. Details are described as follows.

3.2.1 Identifying and analyzing product technologies

According to the design task, the relevant analysis of requirement engineering [7] is applied. Through the requirement analysis of the design task, the corresponding functional requirements and design constraints are determined. Main functions and key technical characteristics are extracted at the same time. An existing mainstream product which can meet functional requirements is selected as a prototype product. Then, the technology system of the prototype product is analyzed for the technical composition and connections of the product.

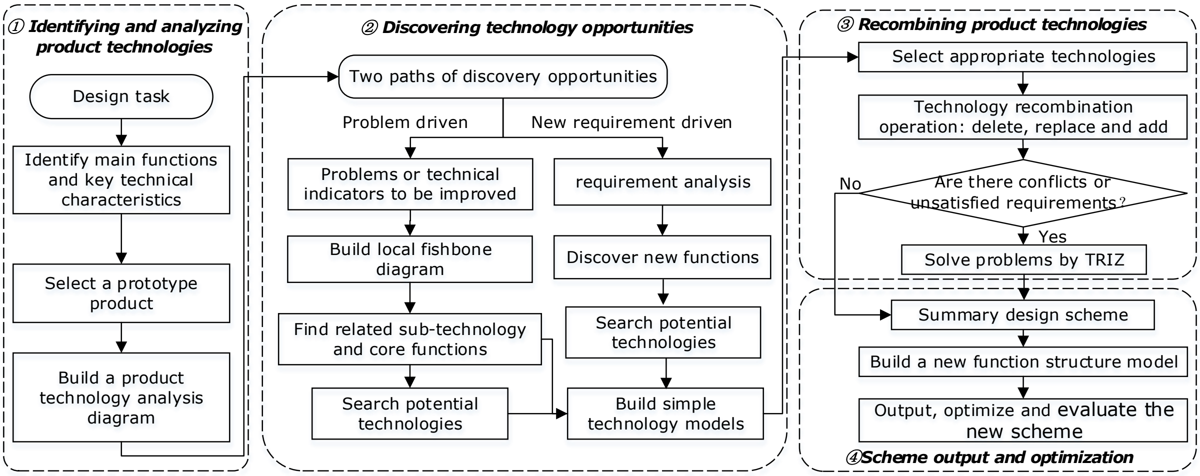


Figure 3: Technology recombination for product innovative design.

3.2.2 Discovering technology opportunities

Technology opportunity discovery identifies potential opportunities of technologies and products [28]. Problem and new requirements are two driven paths to determine objectives of the technological innovation [31].

The problem driven process is applicable to cases with clear problems, or where there are obvious gaps between the existing product and design objectives in technical indicators, such as low efficiency and low accuracy. The key to such innovation is to know the problem accurately and find the root cause of the problem. The fishbone diagram analysis is a qualitative analysis method which looks for the root cause of the problem from aspects of manpower, machine, material, method, measurement and environment, supported by a brainstorming method. In order to simplify the analysis and highlight the focus in the fishbone diagram analysis, the process can start at the problem to search corresponding parts of branches, ignore non-key elements, and draw a local fishbone graph to analyze the root of problem. The sub-technology of the prototype product can be finally clarified with the specific problem. The core function is considered as the key of innovation, meanwhile, function correlations are also considered according to the product technology analysis diagram. A simple technology model can be built to clarify the realization principle and input/output flows of core functions of the product prototype as shown in Figure 4.

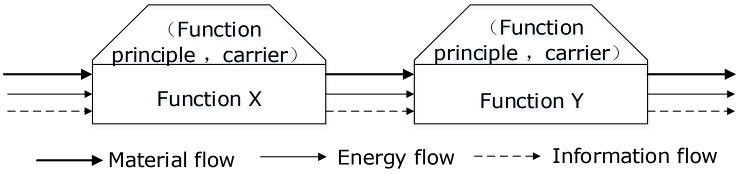


Figure 4: A simple technology model.

For a requirement driven process, some new functional requirements can be obtained through traditional methods such as questionnaires [20], requirements engineering [8], forecasting by the new value profile [17], and patent-based analysis [16]. The innovation goal is seeking technology method for new functions.

Through the analysis of above two paths, innovation opportunities are transformed into searching for potential technologies of core functions. Some existing methods can be used to this process, such as the systems engineering [4] which discovers potential technologies to support the development of corresponding systems and subsystems. Some software tools can be used to find the relevant effect. According to the input/output relationship of effects, an appropriate effect chain is constructed for the potential technology implementation based on designer experience, patent retrieval, and market research. All matching technologies are considered as alternatives of the technology recombination.

3.2.3 Recombining product technologies

The technology composition of a prototype product T= (T1, T2, …, Ti, …, Tn) and potential technologies are obtained in above steps for a recombined technology system. Three basic operations rules are as follows.

1) If there are problems in the sub-technology of the prototype product, and the potential technology meets design requirements, potential technology Tp replaces the corresponding sub-technology Ti to form a new T'= (T1, T2, ⋯, Tp, ⋯, Tn).

2) If the product needs to add new functional requirements, potential technology Tr for a new functional requirement is added into the original technology system to form a new T'= (T1, T2, …, Ti, …, Tn, Tr).

3) According to the requirement analysis, removal defect technology Ti does not affect other technologies, a new technology system can be formed as T= (T1, T2, …, Ti-1, Ti+1,…, Tn).

If multiple sub-technologies need to be recombined, the one with the higher importance rank is recombined first. If the next sub-technology is affected by the first, the technology system will be re-analyzed after the single recombination, otherwise, it can be recombined at the same time. When there are many potential technologies available, the morphological matrix method from TUDelft [19] can be applied.

The recombined technology is expressed as the principle solution or conceptual structure of the new product. The result is then evaluated. The TRIZ tool [26] is introduced to solve any conflict between solutions. Otherwise, the next step should be executed.

3.2.4 Scheme output and optimization

Based on the solution sought for, the technology system and function structure of the new product is established. Technical details are clarified to optimize the design and build a complete technology system. A new function structure can then be built. It is also important to evaluate the new scheme. A method of value engineering [23] is introduced as follows.

$$V_i = F_i / C_i \tag{2.1}$$

where V_i is the coefficient value of scheme i, F_i is the function benefit score of scheme i. C_i is the cost coefficient of scheme i.

Fi is calculated using Equations (2.2) and (2.3):

$$\alpha_{\mathrm{i}} = \sum_{\mathrm{j}=1}^{n} W \times k_{i\mathrm{j}} \tag{2.2}$$

$$F_i = \alpha_i \bullet F_0 \tag{2.3}$$

where F_0 is a standard function benefit score F_0, measurement indicators of F_i are M={M_1, M_2,…, M_n}, corresponding measurement indicator coefficients are W={W_1, W_2, …, W_n}, and indicator completion coefficients of scheme i are k_i={k_{i1}, k_{i2}, …, k_{ij}, …, k_{in}}. The value range of k_{ij} is (0, 1), in which completion measurement indicators are those not completed, completed with serious defects, completed with problem, and well completed for k_m = 0, 0.2, 0.8, and 1, respectively. The expected cost of the prototype product is considered as a standard unit cost coefficient C_0, the cost ratio between the new scheme and prototype product is β_i, so $C_i=\beta_i C_0$.

4 CASE STUDY

At present, Chinese medicinal materials (CMMs) are mostly stored in bulk. There are some problems in the process of CMMs dispensing, such as low efficiency, inaccurate weighing and long processing time. Therefore, there is an urgent need for an automatic quantitative CMMs dispensing machine to improve the efficiency and accuracy of pharmacy dispensing.

4.1 Identifying and Analyzing Product Technologies

After analyzing the product design task, the main functional requirement is "dispensing CMMs", the key technical characteristics are "automatic operation", "configuration speed", "accurate weight", and "safe and reliable". A mainstream automatic quantitative CMMs dispensing machine is selected as the prototype product shown in Figure 5 after analyzing the related equipment and patents.

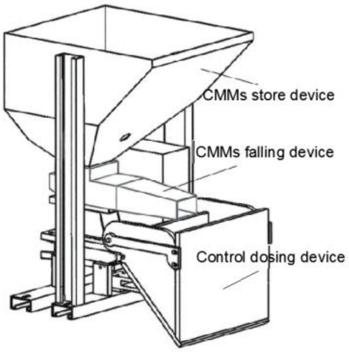


Figure 5: A mainstream automatic quantitative CMMs dispensing machine.

By analyzing the working principle and functional structure of the prototype product, the function structure model and technology analysis diagram are formed in Figures 6 and 7, respectively. The total technology of prototype product is T= (T1, T2, T3, T4).

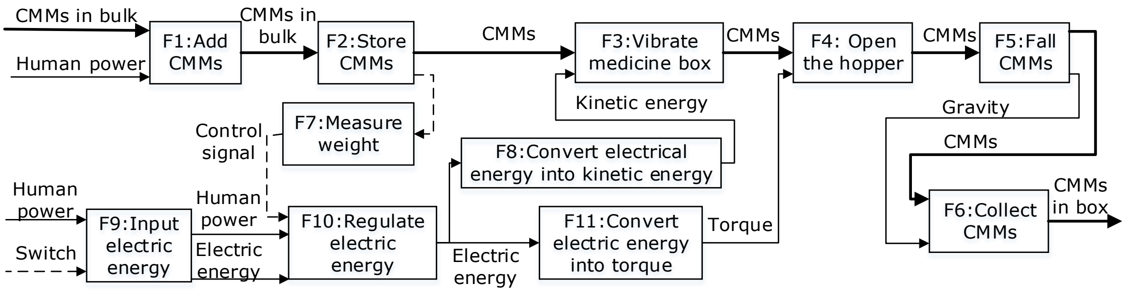


Figure 6: Function structure model of the prototype product.

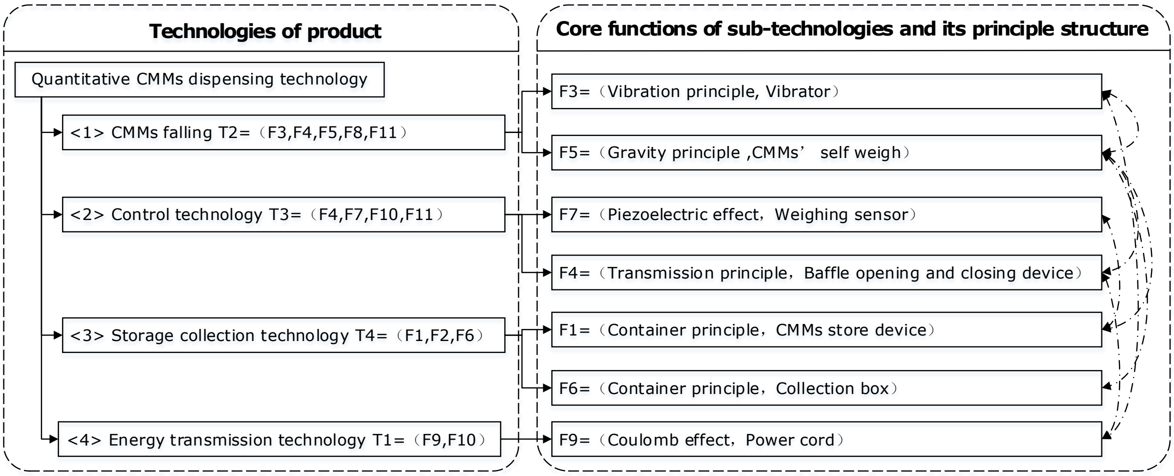


Figure 7: Technology analysis diagram of prototype product.

4.2 Discovering Technology Opportunities

After market investigation and questionnaires, following problems were found in the prototype product: low weight precision Q1, low dispensing speed Q2 and inability to configure continuously multiple pharmaceuticals Q3. As a typical problem driven innovative design, Q1 and Q2 are not satisfied by the existing technology system, and Q3 brings a new functional requirement "continuous dispensing," but it has a strong correlation with T3 and can be used as a technology supplement to T3.

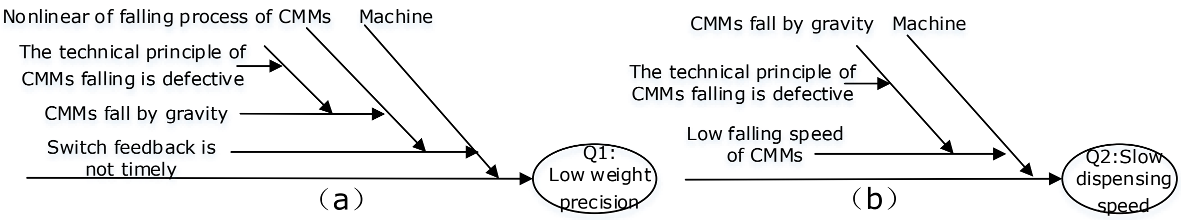


Figure 8: Question analysis based on local fishbone diagrams: (a) low weight precision Q1, (b) low dispensing speed Q2.

Local fishbone diagrams of Q1 and Q2 are shown in Figures 8(a) and (b) respectively. It was found that problem Q1/Q2 mainly occurs in the machine part of the fishbone diagram. It was also found that the main problem is that CMMs falling technology is defective, the result for function "F5: Fall CMMs" of sub-technology T1, a strong correlation function of F5 is "F3: Vibrate medicine box".

According to the key sub-technology obtained from the above analysis, a simple technology model of the prototype product is proposed as shown in Figure 9(a), the corresponding effect chain is "forced vibration → gravity drop". In order to search for potential effect chains, a knowledge base called "effect knowledge base for function realization of different forms of matter" [33] is used, these key functions can be abstracted as function "move solid". The knowledge base is then used to search for available effects: brush, vibration, gravity, Pascal's law, spiral principle, etc. Then, a new effect chain "spiral feeding → gravity drop" is selected according to the difficulty of implementation, the matching of input/output, etc. Its technology model is shown in Figure 9(b). The selected principle structure is a spiral feeding barrel driven by a stepping motor. For Q3, a similar process is used. An appropriate effect chain is then found as "container holding → belt conveying”. The selected principle structure is a conveyor belt with a series of equal capacity cubicles driven by a stepper motor to receive quantitative CMMs.

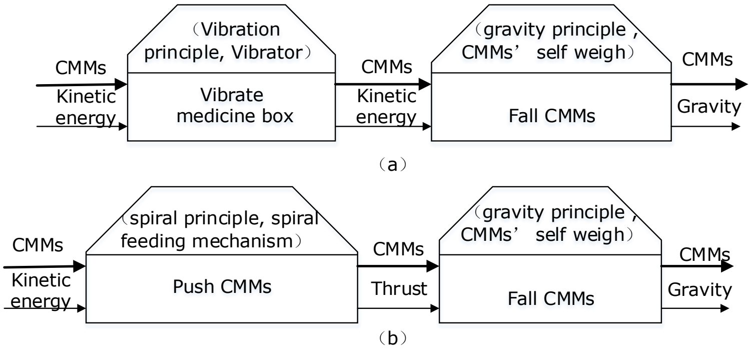


Figure 9: Simple technology model: (a) sub-technology of prototype product, (b) a new scheme.

4.3 Recombining Product Technologies

Based on the above analysis, two functional units are found as “F1’: Push CMMs” and “F2’: Convert electrical energy into rotational kinetic energy 1”, two new potential sub-technologies are obtained: Tp1= (F1’, F2’, F5) and Tp2= (F1, F2, F3’, F6). According to the operation method of the technology recombination, operation rule 2 is selected, TP1 and TP2 can replace T1 and T3 of the prototype product, respectively. A new product technology system T’= (Tp1, Tp2, T2, T4) is formed to meet the requirements without any obvious technical conflict.

4.4 Scheme Output and Optimization

A function structure model of the new product is constructed based on technology system T’ as shown in Figure 10. A 3D conceptual design simulation model and a physical prototype of new CMMs dispensing machine are made as shown in Figures 11(a) and (b), respectively. The machine consists of a screw blanking device, a continuous weighing and collecting device, a CMMs store device and a control device.

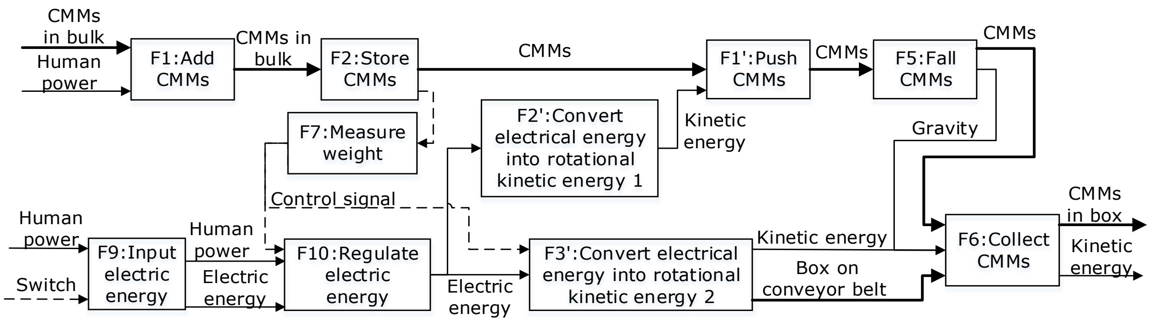
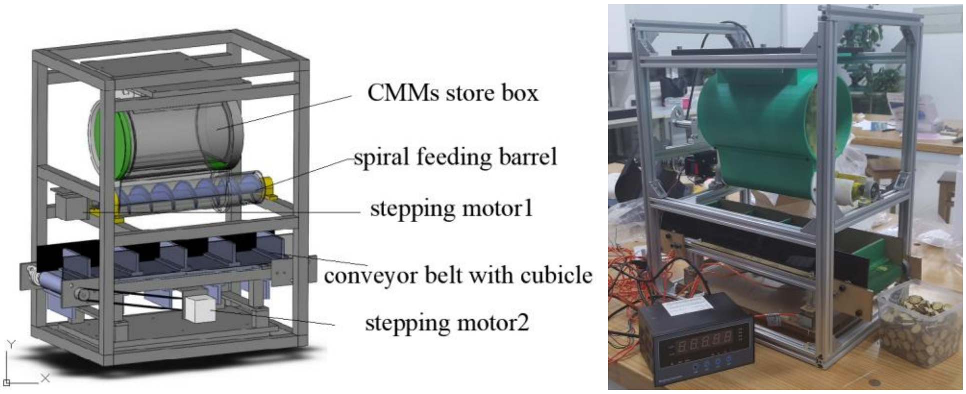


Figure 10: Function structure model of the new design.



（a） (b)

Figure 11: New CMMs dispensing machine: (a) 3D conceptual model, (b) Physical prototype.

According to experts' suggestions and specific conditions, main performance requirements of the product are listed. The most representative four key measures are decided as $M=\{M_1, M_2, M_3, M_4\}$={automatic operation, dispensing speed, accurate weight, safe and reliable}, The Delphi method is used to evaluate uncertain parameters of measures by comparing them with each other according to their importance. After normalization, corresponding coefficients are set as $W= \{0.2, 0.25, 0.3, 0.25\}$ for completion coefficients of the prototype product and new scheme. For the two design versions, the ratio of completion degree to ideal degree under the existing technical conditions is then set. The completion coefficients of the prototype product and new scheme are $k_0=\{0.9, 0.8, 0.8, 0.85\}$ and $k_1=\{0.9,0.95,0.95,0.9\}$, respectively. The cost ratio $\beta_1=1.1$. Finally, all known quantities are calculated using Equations (2.1), (2.2) and (2.3), the results are $V_0=0.8325F_0/C_0$, $V_1=0.9275\ F_0/C_0$. It is obvious that $V_1 > V_0$, so the new scheme is superior to the prototype product.

5 CONCLUSIONS

This paper proposes a method of technology recombination for product innovation design based on the product technology and function analysis. Product innovation based on technology recombination can fully integrate advantages of existing products and potential technologies for an efficient way of innovation. Two paths of the technological innovation opportunity discovery are developed as problem driven and new requirement driven methods for searching potential technologies. Operation rules of the product technology recombination are proposed for the new scheme and solution optimization. Meanwhile, an evaluation method of design schemes is suggested. The proposed method is verified in an innovative design of an automatic machine for CMMs dispensing.

Technology recombination and revolutionary development are also called "thinking out of the box" [1] as two possible ways to develop technical products. Technology recombination emphasizes the recombination of superior technologies obtained from existing products, which can be derived from mature technologies in the existing products, but also can be from novel technologies obtained after "thinking out of the box". Revolutionary development emphasizes the possibility of thinking about technology from a new perspective, which often leads to high novelty technological products that can also be formed by the creative reorganization of technology. Therefore, the technology recombination is often applied in the reuse of existing knowledge, while the revolutionary development relies on the inspiration of independent thinking. But they can be combined in the application. Further work will apply the proposed method to different innovative cases for the method improvement. The proposed method will be developed into a software tool for product design and improvement.

6 ACKNOWLEDGMENTS

This research is sponsored by Chinese Industrial Internet innovation and development project (TC19083W8), the Innovation Methods Special Foundation of Chinese Ministry of Science and Technology (No. 2019IM050200).

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