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Function Integrated Product Innovation Based on Laws of Need Evolution

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Abstract. Function integration is an effective method for product innovation to enhance the product competitiveness in the market. Laws of need evolution can predict potential needs of products. In order to improve the innovative design, this paper proposes a function integrated product innovation method based on laws of need evolution. Firstly, laws of need evolution and strengths-weaknesses-opportunities-threats analysis (SWOT) are used to determine needs of the target product. Products with the function similarity are searched from the patent database. Functions of the similar products are then integrated to meet of the target product. The preliminary solution is obtained by using Theory of Inventive Problems Solving (TRIZ) tools. The innovative solution is formed according to the design priority of the product. Thus, a function integrated product model is constructed based on laws of need evolution for innovative design. Feasibility and rationality of the proposed method are verified by the innovative design of a cleaning device of the oil sump in a range hood.

Keywords: Product function, Function integrated, Laws of need evolution, Strengths-weaknesses-opportunities-threats analysis (SWOT), Similarity, TRIZ
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1 INTRODUCTION

In an increasingly competitive marketplace, the rapid development of new products to meet market requirements has become the core of enterprise competition [11, 17]. Enterprises should respond to market changes through product innovation. But it is a challenge for manufacturers to respond to the requirements with limited resources in a limited time. Function integrated innovation integrates the existing functions to create a new product that satisfies the multi-function needs [15]. It has attracted the extensive attention from academia and industry.

Function integration is one of the important tools for rapid product innovation [14]. Existing research on the function integration mainly focuses on two aspects. One is the research on the definition and characteristics of the function integration. For example, the concept of the function integration, innovative techniques, and their influence on enterprises [12]. The other is the research on innovative methods of function integration. For example, the model of the function integration for product innovation can be formed in the functional level [10]. The bio-inspired design can build multiscale structures for the function integration [16]. The function modeling and TRIZ can be integrated for product innovation design [15]. However, most of the existing methods of the function integration focus on technical elements based on experience of designers, which is subjective and fuzzy in identifying needs and searching solutions for the integrated function. It is difficult to be used in the function integration for product innovation. Therefore, it is necessary to develop an effective innovative design method for the function integration.

Theory of Inventive Problems Solving (TRIZ) is one of the effective approaches to guide designers and engineers understanding design problems for appropriate ideas in the product innovation process [1]. Laws of need evolution is an important concept of TRIZ as one of the tools to solve specific problems in product design. Meeting user needs is the starting and end point of product design. Laws of need evolution have important implications for the evolutionary trend of need from the macro level [23]. If engineers can predict the future needs of users in advance and develop new products purposefully, they will be invincible in the future market competition. Therefore, laws of need evolution can be applied to increase the probability of successful function integration innovative design. In addition, strengths-weaknesses-opportunities-threats analysis (SWOT) is an effective system analysis tool [5]. SWOT can increase awareness and guidance for decision makers. However, most of the existing research of the SWOT is mainly in the field of business and management. Therefore, SWOT is introduced in this research to effectively obtain user needs based on laws of need evolution.

Therefore, this paper proposes a function integrated product innovation method based on laws of need evolution. Firstly, laws of need evolution and SWOT are used to determine needs of the target product. Products with the function similarity are searched from the patent database. Functions of the similar products are then integrated to meet of the target product. The preliminary solution is obtained by using TRIZ tools. The innovative design solution is searched according to the priority of design requirements. Thus, a function integrated product innovative design model is constructed based on laws of need evolution, which provides a systematic method for the innovative product design. Finally, feasibility and rationality of the proposed method are verified by the innovative design of a cleaning device of the oil sump in a range hood.

2 RELATED RESEARCH

2.1 Function Integration

Function integration is an important method for product innovation, which is oriented by market and user needs [28]. Function integration combines one or several functions of the existing product with other products to achieve the supplement, expansion and perfection of product. The new product consists of a variety of product features could not only meet the needs of consumers effectively, but also significantly reduce the risk of enterprises developing such new products. For example, Haruna et al. [6] proposed a process model of the product function integration and structure simplification, and verified the model with a 3D printer as an example. Klaiber et al. [7] proposed a function integration strategy in engineering design from different aspects. Kumar et al. [9] integrated a thermal management for batteries and other functions in the vehicles floor structure. Yang et al. [26] analyzed the status and practical application of function integration in the design of home appliances based on market requirements.

Although the competitiveness of products can be quickly improved through function integration, many enterprises do not have the ability of the function integration, especially small and medium-sized industries. There is subjectivity and fuzzy in searching solutions for the integrated function. Therefore, it is essential to have an operable method of function integration design. Function integration needs to be systematically researched.

2.2 Laws of Need Evolution

Laws of need evolution can predict potential needs of a product. It is summarizing rules for the evolution of human needs, which suggests the direction of product evolution to predict potential user needs [27]. Petrov et al. [20] proposed five laws of need evolution, including idealization of needs, dynamization of needs, coordination of needs, integration of needs, and specialization of needs with their characteristics as shown in Figure 1.

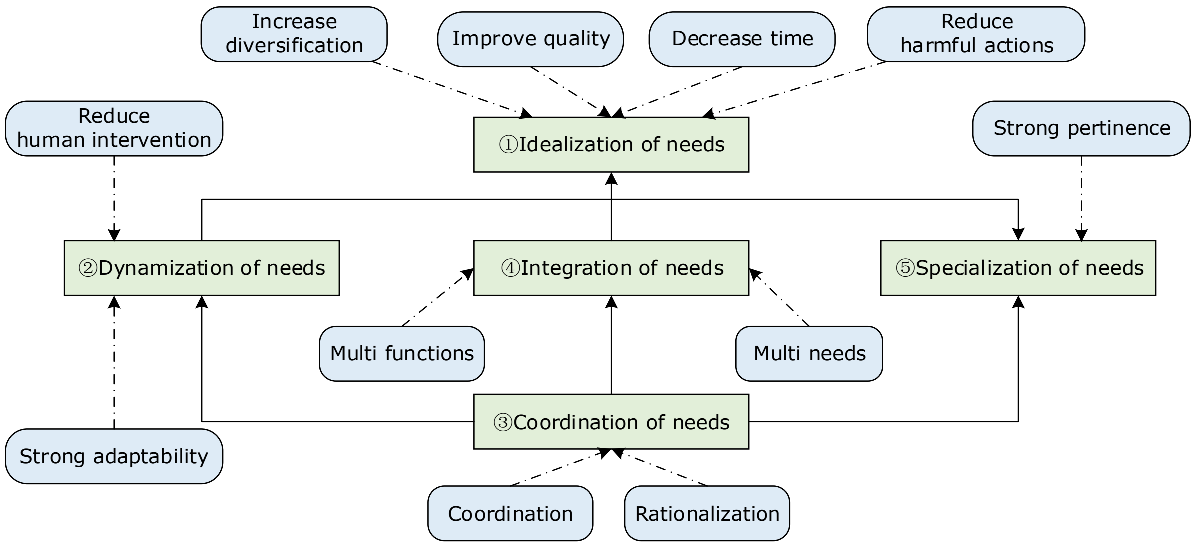


Figure 1: Laws and characteristics of need evolution.

Laws of need evolution are also an important concept of TRIZ. Liu et al. [13] analyzed the performance requirements of the product evolution process based on the laws of need evolution in TRIZ. Laws of need evolution provide tools to solve specific problems of product design. Liu et al. [18] proposed a method of implicit need forecasting for dynamical developing products through the patent analysis and laws of need evolution. Tan et al. [24] proposed a kind of the original innovation process model based on laws of need evolution. Zhang et al. [29] developed a need acquisition process model based on the need evolution and technology evolution.

Although laws of need evolution can help companies to innovative designs, its potential has not been fully exploited. This paper proposes a needs forecasting method based on the existing needs research.

2.3 SWOT

SWOT is an important systematic analysis method, which considers internal and external perspectives to evaluate strengths, weakness, opportunities and threats of functions and other issues of product [21]. Sina et al. [22] proposed a strategic planning approach for post-mining land-uses based on the SWOT analysis and the IE (Internal-External) matrix. Zheng et al. [30] analyzed and forecasted the strategic development of the enterprise based on the SWOT. Zhu et al. [31] used SWOT and ANP to analyze the safety status of electroplating enterprises, and proposed a comprehensive ANP-SWOT analysis model of safety system.

The frequency of using SWOT in product design is far lower than other methods for product design. But SWOT can help engineers enhance design-making awareness. SWOT can be applied to analyze the forecasted needs and make recommendations for innovative design opportunities for the enterprise based on priorities.

3 PROPOSED METHOD

Needs of the target product are identified by using laws of need evolution and SWOT. Integrated function products are searched by applying patents retrieval and product similarity.

3.1 Identifying the Target Needs

Needs of the target product are identified by using laws of need evolution and SWOT. The need in the forecasting process includes satisfied need, predictable need and currently unpredictable need. The predictable need mainly determines the existing knowledge and technology through market research and uses the law of need evolution to predict. Then, predictable and unsatisfied needs are the ultimate goal of enterprise innovation design.

Figure 2 shows the needs forecasting and classification model based on SWOT. In a design process, engineers need to express these needs as design needs, map them into functional needs through axiomatic design and other methods, and finally implement the solution through an innovative design process. According to the type of needs and the impact on the enterprise, needs are sorted in following four categories by applying the SWOT.

(1) W: The disadvantage area of the enterprise. Needs of this area are proposed by users and must be satisfied. Generally, it includes the basic function and total function of the product or technical system, which must be satisfied in the design process. But, if only the basic need is satisfied, it is easy to be hit hard when faced with the market change. We should look for opportunities and avoid weaknesses.

(2) S: The advantage area of the enterprise. Needs of this area have been acquired through surveys but unsatisfied. They are mainly for basic needs of users in the market, enterprises need to fully take their advantages and obtain market competition. In this area, the market competition can be gained by reducing costs, improving performance or certain functions of the product.

(3) O: The opportunity area of the enterprise. Needs of this area are not proposed by users, but they can be predicted. Enterprise engineers can use laws of need evolution to predict potential need to guide innovative design.

(4) T: The threat area of the enterprise. Needs of this area are not proposed and unpredictable in the short term. Such needs are unsatisfied by enterprises. However, the predicted needs will bring great opportunities to the enterprise with the high R&D value.

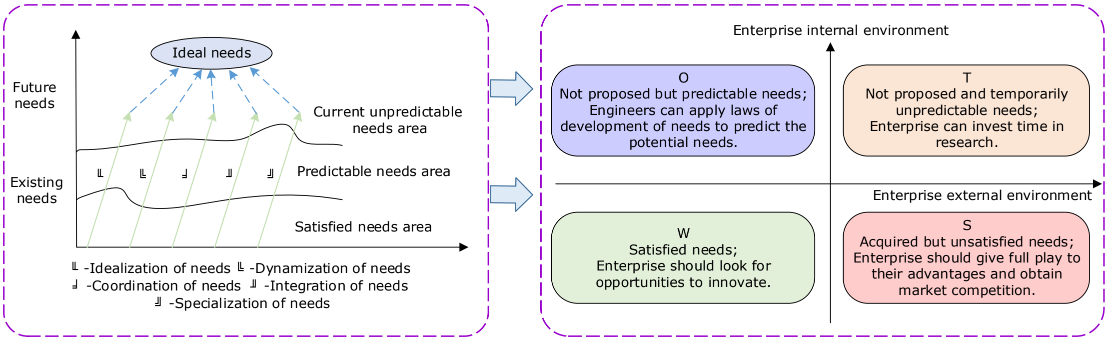


Figure 2: Needs forecasting and classification based on SWOT.

3.2 Identifying Integrated Functions

The integrated function products are decided by searching similarity of existing products. Firstly, the total function of the products is used to determine the function keywords, construct the corresponding retrieval formula for the patent retrieval in the patent database [19]. Preliminarily plans of the integration are decided through patent screening. Then, the functional tree [4] of the product and similarity [2] searching is introduced to select top products as references for the function integration. The similarity between two products is decided by Equations (3.1) and (3.2).

If product A and product B have similar sub-function *j*, and their weights are $w_j(A)$ and $w_j(B)$, respectively, then

$$S = s_j = \frac{\min\{w_j(A), \quad w_j(B)\}}{\max\{w_j(A), \quad w_j(B)\}}, \quad 1 \geq s_j \geq 0 \tag{3.1}$$

If product A and product B have N similar sub-functions, then

$$S = \frac{N}{K+L-N}\sum_{j=1}^{N} s_j \bullet w_j, \quad j = 1, \; 2 \cdots N \tag{3.2}$$

where K and L are the number of sub-functions of an existing product and the integrated function product; N is the number of similar sub-functions between them; w_j is the weight of the sub-function affecting product similarity. $w_1 + w_2 + \cdots + w_N = 1$; s_j is the similarity of sub-functions.

3.3 Function Integration

Function integration combines several functions for the total function of a product. Functions of two products are integrated to meet of the target product as shown in Figure 3. Furthermore, TRIZ tools are used to solve invention problems in the integration process.

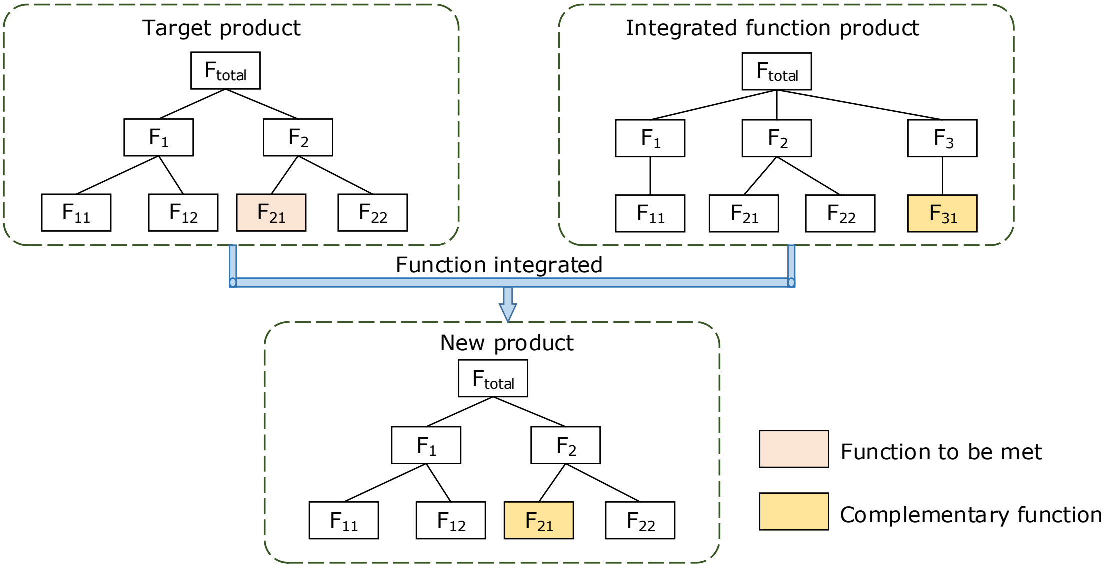


Figure 3: Function integration process of the target product and integrated function product.

3.4 Solution Evaluation

The priority degree evaluation is a method to evaluate the quality of an object [3]. Its steps are as follows: (1) Determining relatively stable and comprehensive measurement indicators $I= \{I_1, I_2, \cdots, I_m\}$ according to design requirements and constraints; (2) Deciding weight coefficients $W= \{W_1, W_2, \cdots, W_m\}$. The Delphi method [8] is one of the approaches to evaluate the measurement indicators. The weight coefficients are determined by comparing, assigning and calculating each indicator based on the expert experience and importance of the indicators; (3) Identifying solutions with necessary conditions; (4) Establishing correlation function K_i and correlation degree $K= \{K_1, K_2, \cdots, K_m\}$ using Equation (3.3); (5) Calculating the priority degree G using Equation (3.4). A larger priority degree G provides a better solution.

$$K_{ij} = \frac{K_i(S_i)}{\max\limits_{q\in\{1,\ 2,\ \cdots,\ m\}} \left|K_i(S_q)\right|}(i=1,\ 2,\ \cdots,\ n;\ j=1,\ 2,\ \cdots,\ m) \tag{3.3}$$

$$G = \sum_{i=1}^{n} W_i \bullet K_{ij}(j=1,\ 2,\ \cdots,\ m) \tag{3.4}$$

where K_{ij} is correlation degrees; W_i is weight coefficients; S_i is the object; G is the priority degree.

An innovative design solution can be obtained according to above steps. Therefore, the innovation design process of the product function integration based on laws of need evolution is shown in Figure 4.

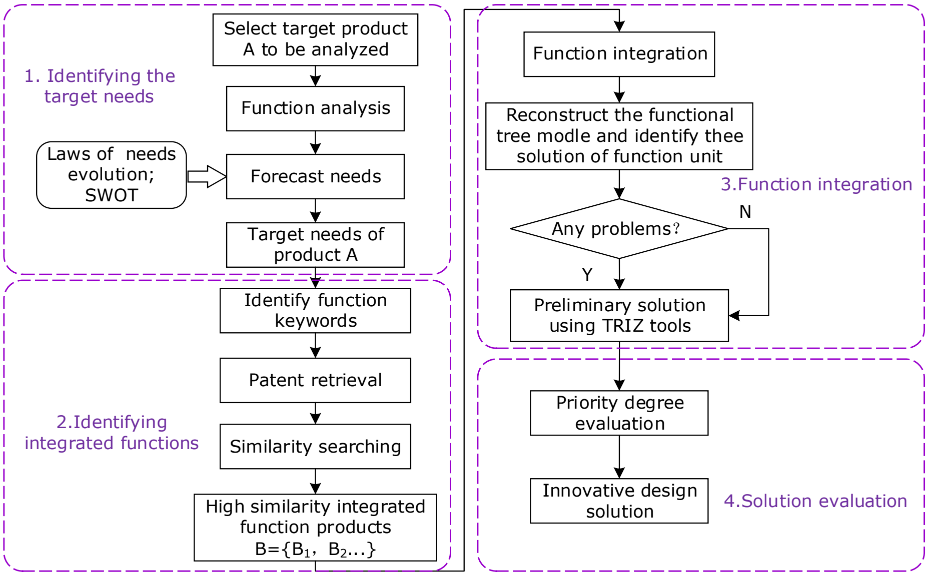


Figure 4: Product function integrated innovation process based on laws of need evolution.

4 CASE STUDY

Figure 5 shows the structure of a range hood [25]. During using the range hood, the oil stain accumulated in the oil sump needs to be cleaned. The existing method is to remove the oil sump for cleaning, which is inconvenient for users. The case study uses the proposed method for an innovative design of the oil sump of the range hood.

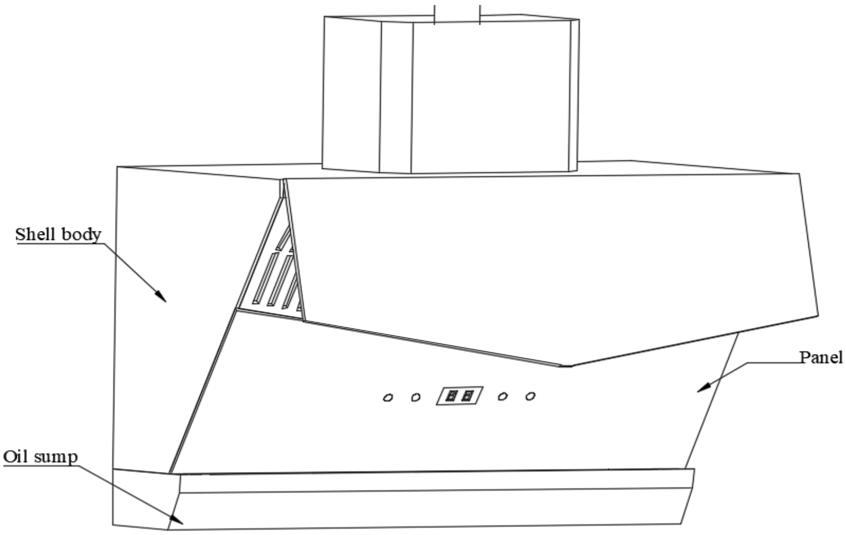


Figure 5: The structure of a range hood.

4.1 Identifying the Target Needs

According to laws of need evolution and SWOT, main needs and target needs of the oil sump cleaning system of the range hood are identified as shown in Table 1. Based on Table 1 and laws of need evolution, the need for the cleaning system of the oil sump of the range hood is obtained. The need is in the opportunity area based on Figure 2.

Number	*Needs*	*Identified needs of the oil sump cleaning system*
1	Increase diversification	It is mainly aimed at the heavy oil in the oil sump
2	Improve quality	Good cleaning effect
3	Decrease time	Reduce cleaning time
4	Reduce harmful actions	No pollution
5	Reduce human intervention	High automation of cleaning system
6	Strong adaptability	The cleaning system is adapted to the sump
7	Coordination	Cleaning system process coordination
8	Rationalization	The cleaning system process is reasonable
9	Multi functions	Both cleaning and monitoring functions
10	Multi needs	Cleaning and monitoring needs are met

Table 1: Needs identification of the oil sump cleaning system.

4.2 Identifying Integrated Functions

Keywords of the total function and potential function needs are determined to construct the corresponding retrieval formula for searching patents in the patent database. Preliminarily plans of the integration are formed by patent screening. The product similarity is then calculated using Equations (3.1) and (3.2) as shown in Table 2. According to the similarity searching, products with integrated functions are determined as "An electrostatic oil fume purifier'' and "Fiber removing device in wet electrostatic oil fume purifier".

Number	*Integrated function products*	*Patent number*	*Similarity*
1	An electrostatic oil fume purifier	CN111111927A	0.7272
2	An integrated stove with oil fume purification device	CN109708173A	0.5294
3	An automatic cleaning device for waste gas discharge filter	CN107213711A	0.6667
4	An automatic oil fume pot cover for removing oil stain on filter	CN104873110A	0.5385
5	Fiber removing device in wet electrostatic oil fume purifier	CN104645738A	0.6981

Table 2: Integrated function products based on similar searching.

4.3 Function Integration

Functional trees are built to model the range hood and two integrated function products as shown in Figures 6 and 7. On this basis, the range hood is integrated with the proposed product for a functional tree of the new product as shown in Figure 8.

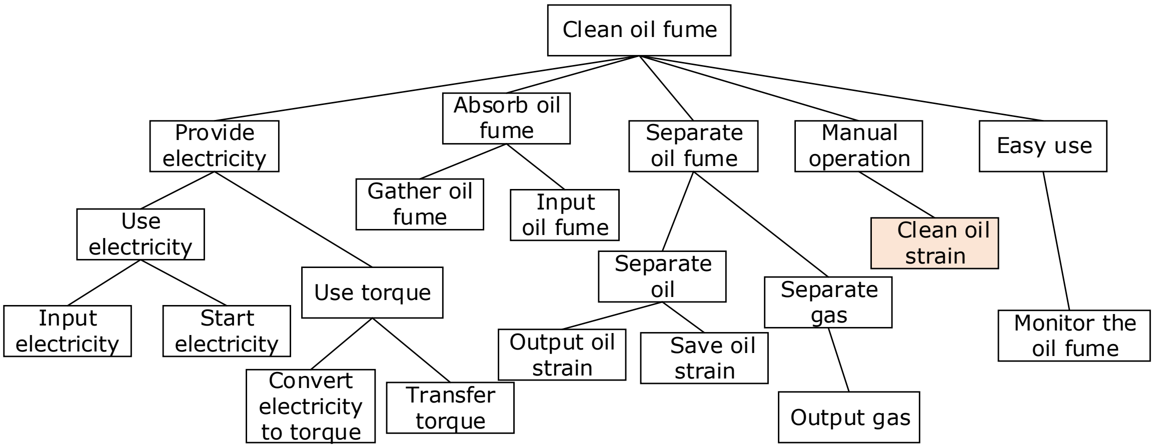
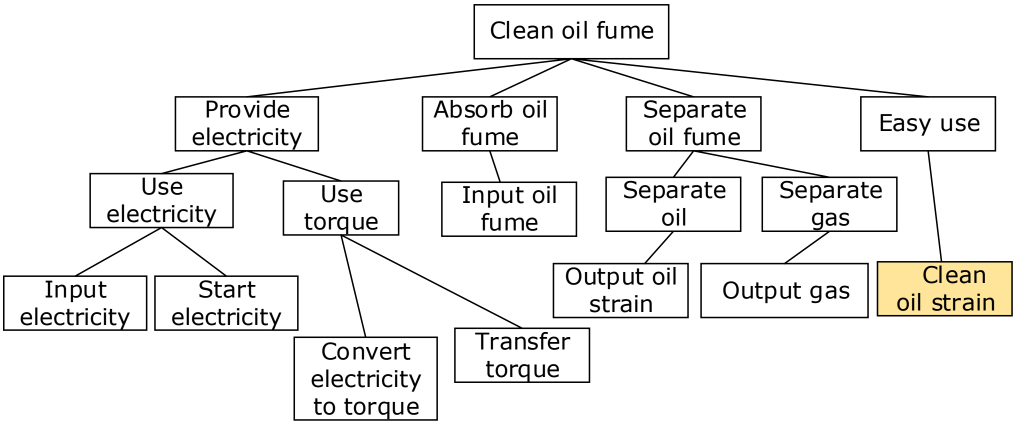
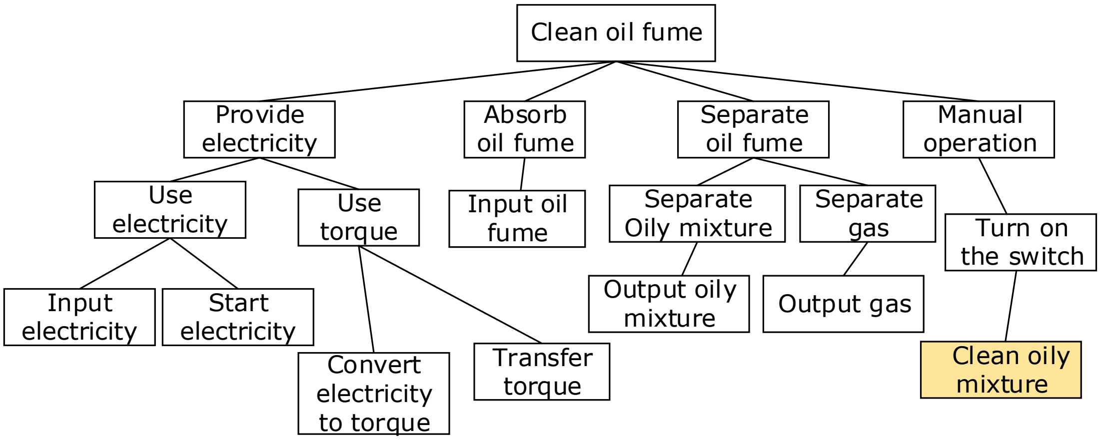


Figure 6: Functional tree of the range hood.



(a)



(b)

Figure 7: Functional tree model of integrated function products: (a) Functional tree of the electrostatic oil fume purifier, (b) Functional tree of the fiber removing device in wet electrostatic oil fume purifier.

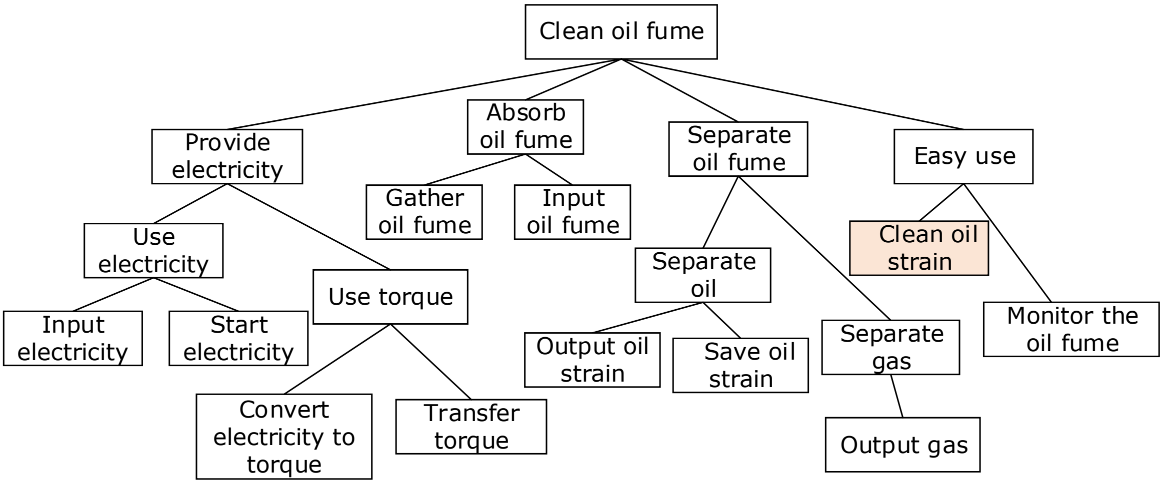


Figure 8: Functional tree models of new product.

According to the functional tree model of the proposed range hood, the preliminary solution is determined as follows:

(1) The function of "clean oil strain" in the electrostatic fume purifier is integrated with the original range hood. The oil sump of the new range hood is cleaned by the scraper. But when the scraper directly on the oil strain in the sump, the scraper will become dirty. The oil strain has a harmful effect on the scraper.

Solution 1: According to TRIZ Standard Solution No. 3 (1.1.3)- If the system cannot be changed, but permanent or temporary external additive changes S1 or S2 are acceptable, solution 1 is obtained. So, the heating tube is set in the scraper to achieve the cleaning effect for the self-cleaning, as shown in Figure 9.

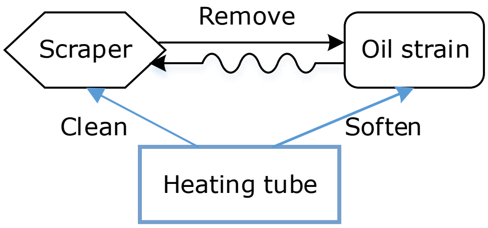


Figure 9: The sub-field model of solution 1.

Solution 2: According to TRIZ Standard Solution No. 9 (1.2.1)- If both useful and harmful effects exist in a system. S1 and S2 are not in direct contact, and S3 is introduced to eliminate harmful effects, solution 2 is obtained. Attapulgite oil absorption purifier is added to the oil sump to quickly absorb and expand the oil-water mixture from a liquid state to a gel-like object, and it is cleaned by a scraper, as shown in Figure 10.

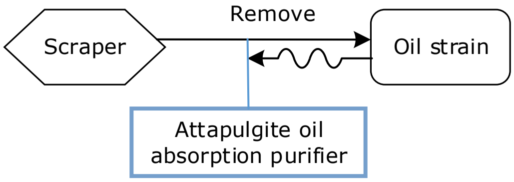


Figure 10: The sub-field model of solution 2.

(2) The function of "clean oil strain" in the fiber removing device in wet electrostatic oil fume purifier is integrated with the original range hood. The oil sump of the new range hood is cleaned by spraying water. But when water is directly on the oil strain in the sump, it cannot be removed effectively as the insufficient power between water and oil.

Solution 3: According to TRIZ Standard Solution No. 14 (2.1.1), the tandem sub-field model, solution 3 is obtained. A micro booster pump is introduced, and high-pressure water is used to clean oil stains in the oil sump, as shown in Figure 11.

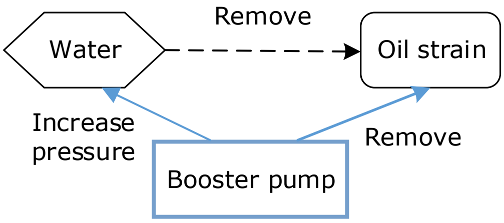


Figure 11: The sub-field model of solution 3.

4.4 Solution Evaluation

Three solutions are evaluated using the priority degree evaluation to determine the innovative design solution as follows.

(1) Determining measurement indicators. According to expert suggestions and design

requirements, the most representative four indicators are determined as $I = \{I_1, I_2, I_3, I_4\}$ = {cleaning efficiency, automation degree, occupied space, cost}.

(2) Determining the weight coefficient. The Delphi method is used to evaluate the measurement indicators of design solutions of the oil sump cleaning device for the range hood using weight coefficients $W = \{W_1, W_2, W_3, W_4\} = \{0.4, 0.3, 0.2, 0.1\}$.

(3) Identifying solutions with necessary conditions. According to required conditions, solutions that do not meet the conditions are removed. The three solutions all meet necessary conditions to clean oil strain.

(4) Establishing the correlation function and calculating correlation degree. For a characteristic value interval of cleaning oil strain [0, 100] and values of indicators of the existing design [50, 50, 50, 50], values of the measurement indicators are obtained by comparing with the original design in Figure 5 as shown in Table 3.

According to $K_i=\{K_i(S_1), K_i(S_2), \cdots, K_i(S_m)\}$ (i=1, 2, …, n), correlation degrees of solutions on measurement indicators are $K_1 = \{70, 75, 60\}$, $K_2 = \{75, 60, 70\}$, $K_3 = \{30, 30, 20\}$, and $K_4 = \{40, 20, 20\}$. Furthermore, standard correlation degrees are calculated using Equation (3.3) as $K_1 \approx \{0.93, 1, 0.8\}$, $K_2 \approx \{1, 0.8, 0.93\}$, $K_3 \approx \{1, 1, 0.67\}$, and $K_4 \approx \{1, 0.5, 0.5\}$.

(5) Calculating the priority degree. Priority degrees are calculated using Equation (3.4) as G(S1)=0.972, G(S2)=0.89, and G(S3)=0.783.

When the oil sump cleaning system of the range hood has the high cleaning efficiency, high degree of automation, small space occupation and low cost, it meets design requirements. The larger values of measurement indicators show the effect of cleaning oil strain. In other words, the optimal solution has the highest priority. According to Step (5), there is G(S1)> G(S2)> G(S3). Therefore, Solution 1 is selected as the optimal solution.

Measurement indicators	*Solution 1*	*Solution 2*	*Solution 3*
cleaning efficiency	70	75	60
automation degree	75	60	70
occupied space	30	30	20
cost	40	20	20

Table 3: Values of the measurement indicators.

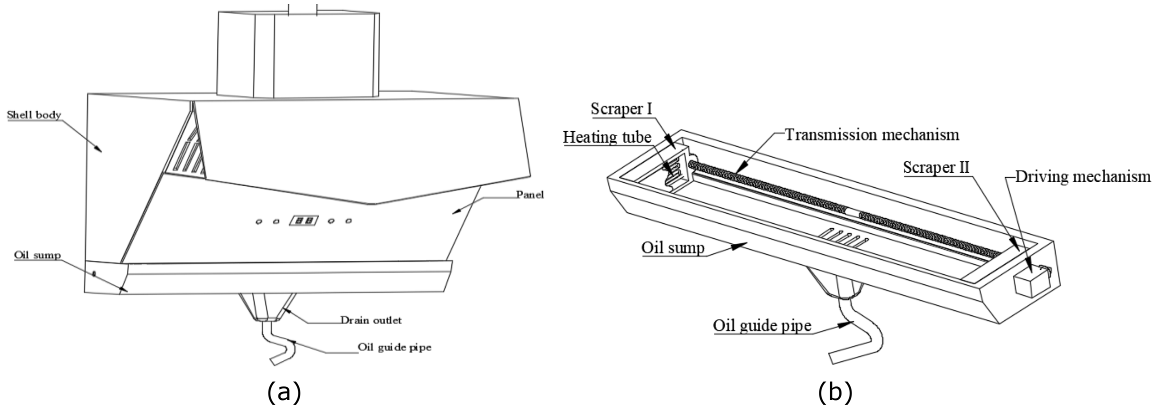


Figure 12: Innovative design solution of the range hood: (a) Overall diagram of the range hood, (b) Overall diagram of the oil sump.

The structure of the final innovative design solution is shown in Figure 12. A drain outlet is arranged in the middle of the bottom of the oil sump and relates to the oil guide pipe. A liquid level detector is installed in the oil sump to control the cleaning time. The heating tube is set in the scraper to achieve the cleaning effect. The working process of the new design is as follows. When the amount of oil strain in the oil sump reaches the preset value, scrapers I and II are heated to a certain temperature, and the oil strain is pushed to the drain outlet and discharged by the pipe. In order to achieve self-cleaning of the scraper, the scraper is stationary at the drain outlet for a period of time, so that the oil on the surface can be melted to flow down.

The design is simple in structure for automatic cleaning of the oil sump with the high use value. The comparison results with existing products as shown in Table 4. Although the new product is slightly more expensive than product 2 and product 3, it can automatically clean the oil sump. Comparing with product 1, although the new product has a slight disadvantage in the material of the sump, but the price is low and it can be self-cleaning, which has a high cost performance. Therefore, the device has good commercial prospects for production.

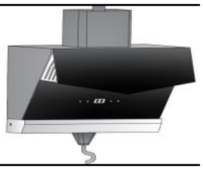
Product information	*Products in the market*			*New product*
	Product 1	*Product 2*	*Product 3*	*Product 4*
Product image				
Price	22800	1199	2199	2499~2999
Material of sump	Galvanized steel (Oil repellent coating)	Transparent plastic	Stainless steel	Stainless steel
Cleaning method of sump	Manual cleaning	Manual cleaning	Manual cleaning	Self-cleaning
Is the sump easy to clean? (1-4; 1 is the easiest; 4 is the most difficult)	2	4	3	1

Table 4: The comparison with existing products.

5 CONCLUSTIONS

A method is proposed for the function integrated product innovation based on laws of need evolution. The method provides ways for innovative design of product. Laws of need evolution and SWOT are applied to decide needs of a target product. Integrated functions are decided by similarity searching in the patent database. Functions of similar products are integrated to meet needs of the target product. Solutions are achieved by applying TRIZ tools. The innovative design solution is decided by the priority degree evaluation. The proposed method is verified in the innovative design of a cleaning device of the oil sump of the range hood.

6 ACKNOWLEDGEMENTS

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