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Function Combination of Product Reconfiguration based on Scenario Analysis

Limeng Liu[1], Runhua Tan[2], Qingjin Peng[3], Wei Liu[4], Huangao Zhang[5] and Jinpu Zhang[6]

[1]Hebei University of Technology, liulimvp@163.com
[2]Hebei University of Technology, rhtanhebut@163.com
[3]University of Manitoba, Qingjin.Peng@umanitoba.ca
[4]Hebei University of Technology, lwofhebut@126.com
[5]Hebei University of Technology, zhgzwy@hebut.edu.cn
[6]Hebei University of Technology, jinpu_zhang@163.com

Corresponding author: Runhua Tan, rhtanhebut@163.com

Abstract. Function combination of products can save resources and improve product function diversity. The combination is a process of integrating and optimizing functional elements of products according to function requirements. In order to improve feasibility of the function combination in product design, a method of product reconfiguration is proposed in this paper based on scenario analysis. New product functional units are obtained through searching inner and super systems of product scenarios. The prototype product execution module of new functions is integrated into an existing product to simplify the design process. An effective Su-field model of the existing product is abstracted as the basic support module to the original product. 76 standard solutions of TRIZ tools are applied in the design to reconstruct a new product for functional combinations. The proposed method is verified in the innovative design of functional combinations of an electric blower product.

Keywords: Scenario analysis, Function combination, Functional unit, System reconfiguration, Su-field model
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1 INTRODUCTION

Enterprises have to constantly improve their products to maintain competitive advantages in the market. For the function improvement, the product evolution from a single function to multi-functions follows an innovation path in line with the market trend [24]. Function combination is a process of integrating and optimizing functional elements of products according to function requirements. The combination can improve the integrity and creativity of a product by integrating different functional characteristics into a single functional carrier [2].

In order to assist designers in the function combination, some systematic innovation methods and key processes in function combinations have been proposed, such as the reconfigurable design method [9] to reuse existing product components and develop new components from new functional requirements. Adaptive design methods [7] emphasize the adaptability of products in a design process of modifying products to meet the change of functional requirements. Comprehensive design methods [19] establish work step plans for designers in each design stage to form a complete design process. The contact and channel approaches [1] improve the tool support for integrated product models at the system level. Agile design methods [16] provide a rapid response design process based on the environmental change for the mechatronics system integration. Mizoguchi et al [18] established the functional ontology to standardize function combination relationships. Liu et al [12] proposed different functional combinations according to corresponding biomaterial characteristics. Liu et al [11] introduced TRIZ (theory of inventive problem solving) to solve design problems in the function combination. Mcadams et al [17] proposed different products based on similarity. The similarity analysis of products was used to assist the innovative design of multi-functional products. Zou et al [24] developed a functional design method for variable functions of mechanical products using the function similarity. Although the existing methods have made progresses in the function combination, there is a lack of discussions on sources of combined function units. Traditional methods such as questionnaire [19], forecasting by the new value profile [26], and patent based analysis [15] can obtain some function requirements, but they are not very mature. The extracted requirements are relatively scattered, and the relevance among functions are not strong. But the scenario analysis can help designers to find new needs and make correct decisions [20]. New functional requirements extracted by the scenario analysis have a strong matching for future applications of the product. For the product reconfiguration, the existing methods are complex in use.

Innovation comes from the exploration of different design scenarios [10]. In this paper, a method of the scenario analysis is proposed to explore product function requirements and decide potential functional units. A product system is reconstructed according to relations of functional modules. By abstracting relations between modules into abstracted Su-field models, the system contradiction can be found, 76 standard solutions of TRIZ tools [21] are then applied to solve the system contradiction. An innovative design process for function combinations of products is developed. The function combination design of a hair dryer verifies the proposed method.

2 PROPOSED METHOD

2.1 Scenario Based Reasoning of Functional Requirements

Product design is a scenario analogy process to meet function requirements [5]. The product application is based on the rule evolution of the scenario [8]. Possible scenarios or circumstances are capable to provide useful hints for the development of new products [4]. Scenarios can be used to find required functions of product. According to scopes of the scenario analysis, scenarios can be divided into inner system scenario and super system scenario. The former searches function requirements by analyzing the impact of changes in relevant scenario elements on product actions. The latter finds possible scenarios before and after the product applications to deduce possible functions through the expansion of product applications.

2.1.1 Functional units decision based on inner system scenarios

Existing products provide functions of specific requirements. The harmonious unity of products, users and environments is the basis for products to play their expected functions. Changing or expanding relevant elements and constraints can affect changes of the demand to stimulate the generation of new required functions. Figure 1 shows the decision process of functional units based on the scenario analysis. There are five steps for designers to find potential functional units based on the inner system scenarios analysis as follows.

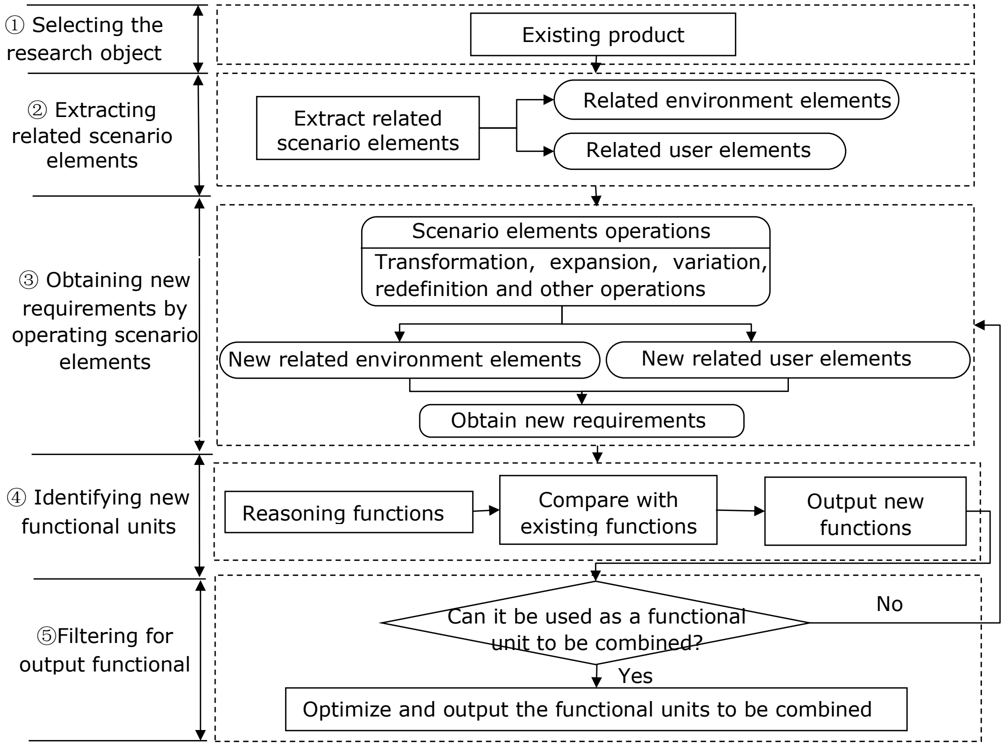

Figure 1: Decision of functional units based on scenario analysis.

1) Selecting the research object: Designers select an appropriate existing product as the research object to define main functions of the existing product after fully analyzing the design task.

2) Extracting related scenario elements: A series of abstracted expressions of basic concepts, attributes and relations of objective things related to product scenarios are called scenario elements with necessary conditions to support the scenario evolution. Generally, scenario elements belong to resources of a scenario system. In order to find all relevant scenario elements, we can refer to the resource analysis method in TRIZ to analyze the existing product, and classify two types of inner system scenario elements that affect the product design: related environment elements and related user elements. The former is product factors in the action environment including material, energy, space and time. The latter is user factors, including user age, gender, and behavior.

3) Obtaining new requirements by operating scenario elements: For the operation of product related scenario elements, designers need to combine experience with reasonable divergent thinking to restructure the product's future environment and target objects as follows.

For the related environment elements, designers analyze environmental resources by gradually reducing the scope from large to small, associate the geographical area and application site characteristics of the possible application of the product, set the future action environment of the product, and extract the related environment elements that may affect the product design from different sites. At the same time, for existing elements, the transformation, expansion and variation can be carried out. Operations such as redefinition can also be introduced for new elements or constraints.

For the related user elements, designers can select appropriate restrictions from users' age, gender, language and behavior to extract new related user elements according to future object-oriented products.

The change of these product related scenario elements makes the existing products unable to support the expected scenario evolution process, so designers can consider new users and new environment elements as the new design task for new user requirements.

4) Identifying new functional units: According to the new user requirements extracted in the previous step, designers can obtain new functional units by mapping relations between the new user requirements and new functional units. By comparing with functional units of the existing products, new functional units are selected for improving the existing products.

5) Filtering for output functional units: Function combination is not a random process of the function improvement, but a combination for a specific goal [3]. Designers need to screen new functional units when they infer them. Two simple conditions need to be considered: the new function cannot conflict with the main function of the product, and the related structure of the existing product can assist the expected execution structure of the new function to work without great changes. The new functional unit after screening can be used as the functional combination unit of potential products. According to the enterprise requirement and market feedback, designers can select one or several functional units to be combined to the existing product in the product detailed design.

2.1.2 Functional units decision based on super system scenarios

The product application is a continuous process with a series of behavior scenarios. Designers can simulate the behavior of the product through the expected scenario. Application scopes of the product can be expanded if these behaviors can be mapped into corresponding product functions using the behavior-function scenario analysis as shown in Table 1.

Behaviors	*Required functions*	*Function carrier*	*Functional combination unit*
Behavior B_1	Function F_1	Product prototype or mechanism with F_1	Yes\No
Behavior B_2	Function F_2	Product Prototype or mechanism with F_2	Yes\No
···	...	Product Prototype or mechanism with F_a	Yes\No
Behavior B_i	Function F_i (main function)	Existing product	Yes\No
···	...	Product Prototype or mechanism with F_b	Yes\No

Table. 1: Behavior-function scenario analysis.

Table 1 lists the scenario evolution of a whole product action process, including both preparation in the early using stage and processing in the later stage. The action process of these super systems plays an important role in the realization of the overall action. Other functional requirements besides the existing product functions can be regarded as potential functional units. Designers can decide whether they can be used for the functional combination. The fifth step of the previous section can also be used for designers to decide whether a new function and its carriers matches the existing product to select the appropriate functional unit.

In Table 1, function carriers describe existing products or mechanisms used to complete functions. Behaviors are arranged in a chronological order. The table only lists the situation in which one behavior is performed at the time. If there are multiple behavior operations required at the same time, a corresponding enlargement can be made on the right side of corresponding columns of behaviors, required functions and function carriers.

Designers may get multiple potential functional units through the scenario-based analysis, but not every combination of new functional units is suitable for the launch of new products of enterprises. According to the comprehensive consideration of the market demand, enterprise strategy and technical reserves, designers can choose to combine one or more new functions with original product functions. When we combine multiple functions, two selected functions are combined firstly, and other functions are then added one by one to complete the entire design.

2.2 Product Reconfiguration Based on Function Combination

Designers can search more potential combined functional units through the product scenario analysis for the reconstruction of a product technology system. The corresponding product functional structure can then be formed. Traditional functional structure solving methods such as FBS [6] and axiomatic design [22] can be used to complete the conversion from function to structure, but it is equivalent to a process of redesigning products with a long design cycle. Therefore, a new method of the product reconstruction is proposed as follows.

In an actual product system, the reconfiguration takes existing products as starting examples of combined functions. Function combinations is to form a product with new features in the existing product. The whole process is designed to fully inherit main functions of existing products in four stages as shown in Figure 2.

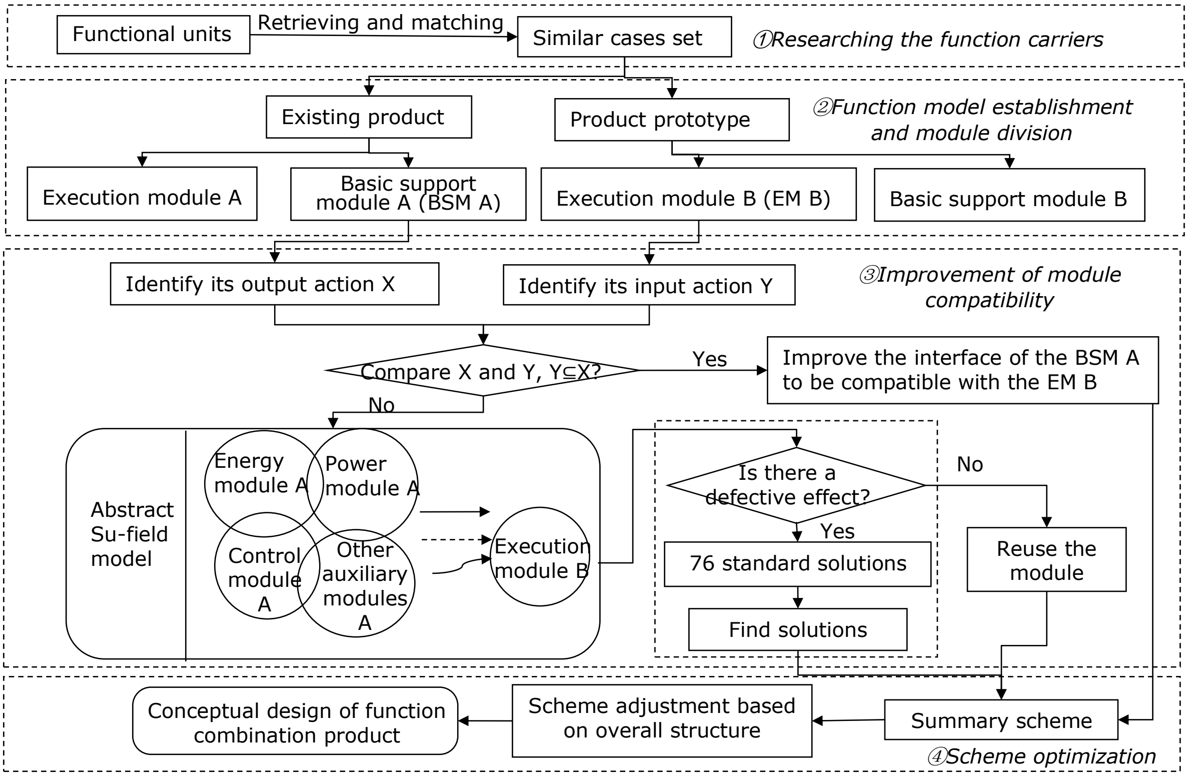

Figure 2: Product reconfiguration based on relations of product function modules.

2.2.1 Searching for function carriers

For the implementation of functional units, designers search for similar case sets that can satisfy functional units by experience or searching patents. It should be noted that cases with the simple structure and mature technology should be given priority in selection.

2.2.2 Function model establishment and module division

The function model is a result of the function analysis. By building a function model as shown in Figure 3, interaction and connection relations of a product structure can be visually identified. Considering the integrity of a technical product system, the function structure model of a complete technical system can be divided into energy module, power module, execution module, control module and other auxiliary modules. At the same time, we consider other modules except the execution module as basic support modules of the product.

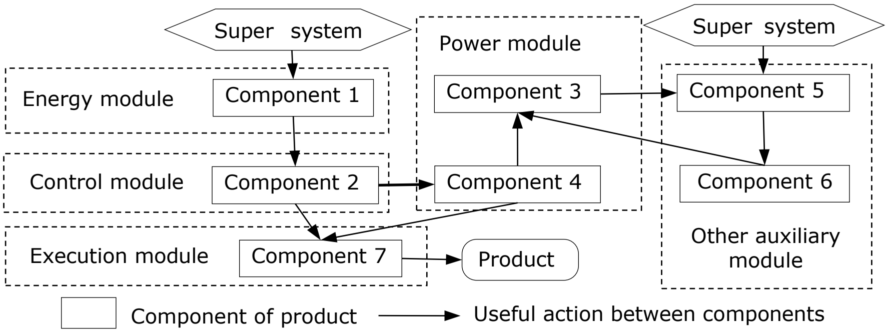

Figure 3: Product function structure model.

By building functional models of existing products and prototype products based on corresponding modules, designers can form the executive module and basic support module of existing products and product prototype, respectively, as shown in Figure 2.

2.2.3 Improvement of module compatibility

The similarity of different systems is usually manifested underlying behavioral processes and their corresponding structural components. However, it is difference from purposeful behavioral processes that result in different functions of different products [25]. For a complete product system, its execution module accomplishes the main behavior purpose of the product, including necessary product institutions to complete defined functions. The other modules to support the execution function can be summarized as basic support modules. Therefore, existing support modules can be improved to be compatible with the execution module of a product for the functional combination.

At this stage as shown in Figure 2, designers first identify output action X of basic support module A and input function Y of execution module B to compare them. If they are compatible, the existing product execution module can be improved directly. Otherwise, the existing product should be rebuilt to provide required functions of the execution module of the product to meet existing product functions.

There are some methods [14, 15, 28] for improving compatibility of modules, but their processes are complex and time-consuming. In this paper, the abstract Su-field model is introduced to accelerate the design process. If basic support modules in the existing product are abstracted as substance S1, and the execution module of the prototype product is abstracted as substance S2, their action relationship can be abstracted as field F. A module action characteristic comparison can be made by abstracted relations of corresponding modules in Table 2. There are four typical functions of abstracted Su-field models as shown in Figure 4. In addition to the Su-field model, we define other three models as the defective material field model. It should be noted that the function between support modules in the existing product and its execution module is defined as an effective and completed function.

Therefore, a product system reconfiguration can be transformed into an improvement problem of function modules. The problem can then be solved by using 76 standard solutions for the defective substance-field model in TRIZ under standard conditions in five categories: no change or only little change for the system improvement, system change, transferring system, detection and measurement, simplification and improvement strategy [23]. They provide suggestions for applications of standard solutions to guide and enlighten improvement ideas step by step. Comparing with the established TRIZ tool, the proposed abstract model extends the application scope of the traditional Su-field model, 76 standard solutions are used to inspire design thinking. The generated scheme is for not only a single material or field, but also a set of components with the demand characteristics.

Product module	*Module action features of existing product*	*Module action features of product prototype*	*Differences between modules*	*Abstract functional action relationship*
Energy module	Ways and types of energy supply 1	Ways and types of energy supply 2	Differences between energy supply	Functional type A
Power module	Ways and characteristics of power generation 1	Ways and characteristics of power generation 2	Differences between power generation	Functional type B
Control module	Control process and method 1	Control process and method 2	Differences between control ways	Functional type C
Other auxiliary modules	Basic action features of other auxiliary module 1	Basic action features of other auxiliary module 2	Statement of differences	Functional type D

Table 2: Module action characteristic comparison.

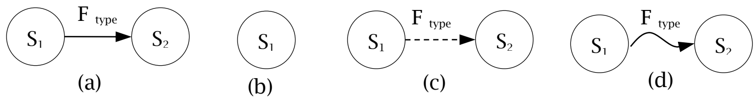

Figure 4: four typical functions of the abstract Su-field model. (a) effective and complete function, (b) incomplete function, (c) non-effective and complete function, (d) harmful function.

2.2.4 Scheme optimization

Through the reuse and improvement of function modules, basic support modules of existing products can be compatible with execution modules of the prototype product. The next step is to summarize and adjust the overall scheme for universality of the product interface and optimize the relevant auxiliary structure according to the design experience and demand. For example, a variety of actuators can be integrated into a product, and finally form a complete conceptual design scheme.

In this phase, it is also important to decide values of the innovative design scheme. Related methods of value engineering [21] is introduced by comparing the new conceptual product and existing/prototype products to evaluate the design solution. This evaluation method mainly decides the value coefficient of each scheme. The larger the value coefficient is, the better the technical economy of the mode is. The value is decided by Equation (2.1).

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

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

In order to facilitate the process, we only compare value parameters of the new design scheme with existing products and prototype products, so the score here is only for main functions. Main functions of existing products are set as a score of standard unit 1.0 F_0. Customers are then invited to score corresponding functions extracted from the product prototype and new scheme respectively for the relative importance of their demand performances. Finally, experts summarize, filter and process the data to obtain relative function scores $\alpha 1F_0$ and $\alpha 2F_0$. It is assumed that the existing product has a standard unit cost coefficient 1.0 C_0. The prototype product and new scheme are evaluated as $\beta_1 C_0$ and $\beta_2 C_0$ through the market inspection. Finally, the relative cost coefficient of each product, $V_0=F_0/C_0$, $V1=\alpha_1F_0/\beta_1C_0$, and $V_2=\alpha_2F_0/\beta_2C_0$ can be decided.

3 CASE STUDY

Electric blower is a small electrical appliance commonly used in daily life. It is mainly used for hair drying and shaping. There are many competitive products in the market. In order to increase the market share, the blower can be improved through the combination of functions to expand its applications for diverse requirements of users.

3.1 Analyzing Products and Identifying Functional Units of Existing Products

Commonly used handheld centrifugal hairdryers in the market were collected and analyzed. The main function of the product is to provide the warm air.

3.2 Searching for New Functional Units

There are two different methods to search potential functional units as follows.

1) Function units decision based on inner system scenarios: The existing product is an electric blower commonly used in environments such as space occasions, homes, barber shops, and physiotherapy rooms. Material resources include wet hair, dry hair, non-clean hair and residual hair breakage. The field resource is power. Information resource has feedback on the status of hair, and user resources are people. Our operational searching process for relevant scenario elements is as follows.

We select the key scenario as cleaning the hair and residual hair on the ground. The scenario elements of the residual hair on the ground are transformed into collected hair breaks. The new required function is expanded to “collecting hair breaks”. We also add the hot air as a related scenario element for expanding the new functional requirement for “providing flowing wind”.

2) Functional unit decision based on super system scenarios: A barber shop is selected as the product working place. According to behaviors of customers in barber, a barber behavior-function scenario chart is built as shown in Table 3.

Behaviors	*Required functions*	*Function carrier*	*Functional combination unit*
Wash hair	Clean hair	Shampoo facilities	No
Wipe wet hair 1	Remove some moisture	Towel	No
Cut short hair	Cut short hair	Electric barber	Yes
Blow away the broken hair	Supply warm air	Electric blower	Yes
Wash hair 2	Clean hair	Shampoo facilities	No
Wipe wet hair	Remove some moisture	Towel	No
Blow dry hair	Supply warm air	Electric blower	Yes
Clean up broken hair	Collect broken hair	Vacuum cleaner	Yes

Table 3: Barber behavior-function scenarios.

According to Table 3, in the whole process, there are three remaining functions in the second column in addition to the function of the hair dryer to provide warm air. Based on the existing function carriers, it can be seen that the overall structure of the shampoo table to clean hair and towel to remove part of moisture is far from the main function carriers, so it is not a suitable functional combination unit. However, the main functional principle, implementation mode and structural feature of the basic support module of the electric barber are similar to those of the electric blower. The function of “cutting short hair” can be selected as a functional unit combined with function of “providing the hot air”.

Therefore, "collecting broken hair", "providing flowing wind" and "cutting short hair" are three potential functional units to be combined in a new product. After a further analysis, these three functions can be well supplement functions of the existing products. As the demand of "collecting broken hair" function is relatively small for electric blowers, here we take the combination functions of "providing warm air" and "collecting broken hair" as an example to show the process of product reconfiguration. The combination of additional functions can be followed in a similar process.

3.3 Product Reconfiguration Based on Function Combination

There are four steps to conduct the product reconfiguration for both functions of "providing warm air" and "collecting broken hair" based on the existing products as follows.

1) Searching the function carrier: After analysis and inspection of mature products on the market for the function of "providing warm air", all kinds of electric blowers are identified. While products for the function of "collecting broken hair" are all kinds of vacuum cleaners. Considering the technology and equipment cost, and similarity of the products, we choose a commonly used plug-in electric blower and a plug-in centrifugal vacuum cleaner as the existing product and prototype product respectively to conduct the function combination design.

2) Function model establishment and module division: In order to define the functional structure characteristics of the product, functional structure models of product prototypes are formed as shown in Figures 5 and 6.

3) Improvement of module compatibility: In order to clarify the compatibility of related modules, the module action characteristics are compared in Table 4.

From Table 4, it is identified that the energy model of the new system is an effective and complete function, while the power module, control module and other auxiliary modules have defective functions. To improve the corresponding modules, an abstracted Su-field model is built as shown in Figure 7. 76 standard solutions of TRIZ are selected to solve the problem as shown in Figure 7.

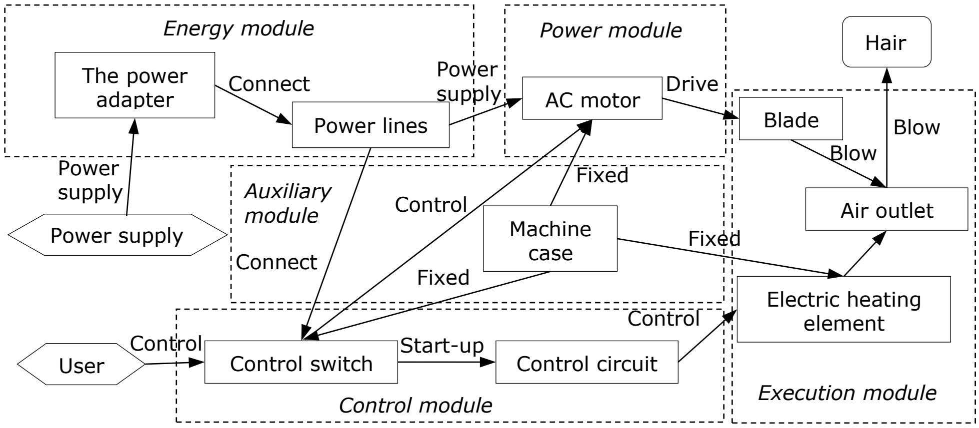

Figure 5: Function model of electric blower.

Figure 7(a) shows an incomplete function. According to 76 standard solutions in TRIZ, standard solution 1.1.2 is selected to add a fan impeller for the suction function. Standard solution 3.1.2 is applied to improve the motor connection of the fan blade of the hair dryer and the fan impeller of the vacuum cleaner. Two powered fans are shown in Figures 8(a) and (b).

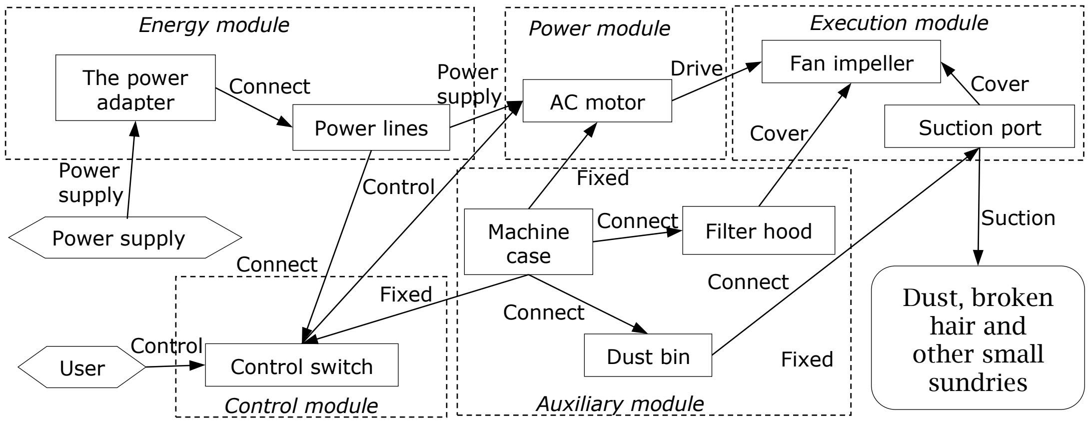

Figure 6: Function model of the vacuum cleaner.

Basic support module	*Module action features of vacuum cleaner*	*Module action features of electric blower*	*Differences between modules*	*Abstract functional action relationship*
Energy module	Socket outlet provides standard AC	Socket outlet provides standard AC	No obvious difference, can directly reuse.	Effective and complete function
Power module	Providing rotational kinetic energy to generate wind energy, which is oriented towards the air outlet.	Provide large rotational kinetic energy to generate wind energy. The direction is far away from the air outlet.	There is a gap in the speed of the motor, and there is a difference in the direction of generating wind energy.	Non-effective and complete function
Control module	Controlling the power supply of motor and electric heating element.	Controlling the power supply of the moto.	The control module of electric blower controls the electric heating element to affect the dust collection effect.	Harmful function
Other Auxiliary Modules	The shell is used to fix the components and restrict the air flow direction.	Fixing and connecting components with debris collection and filtering device.	The auxiliary module of the electric blower can provide fix and connection functions, but it cannot realize the collection and filtering functions.	Non-effective and complete function

Table 4: Module action characteristic comparison of the vacuum cleaner and electric blower.

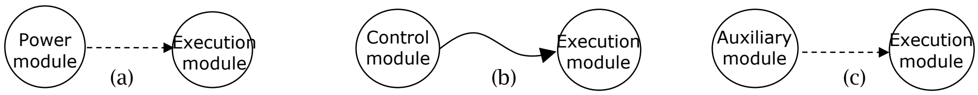

Figure 7: Abstracted defective Su-field model.

The Su-field model shown in Figure 7 (b) is a harmful function because the electric heating element controlled by the blower control module will affect the dust collection effect. Standard solution 1.2.1 is used to have a switch to control the electric heating element to eliminate the harmful effect. A circuit is built to control the electric motor power supply and electric heating element power supply separately, as shown in Figure 8(c).

Figure 7(c) also shows an incomplete function. Standard solution 1.1.2 is used to add a dust collection bin and filter cover. Standard solution 3.1.2 is also used to improve the shell shape for connecting the dust collection bin and filter cover. As shown in Figure 8(a), the executive part of the vacuum cleaner is separately constructed as a switchable module.

4) Scheme optimization: Through the reuse and improvement of the above product modules, we have obtained a conceptual design scheme of the product structure. After the adjustment of details, a new functional combined product is formed with basic functions of the electric blower and vacuum cleaner as shown in Figure 8. It is composed of a main body and two conversion heads to perform different functions.

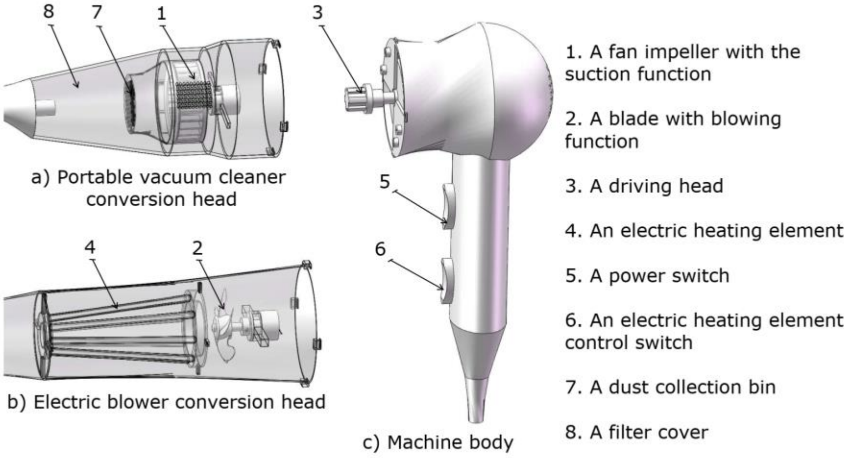

Figure 8: Conceptual design of new product.

According to the analysis of mainstream users and application environments, the main function of an electric blower is identified as ”providing warm air”，it is set as a standard function scope F_0. The main function of a vacuum cleaner is "collecting dust", we set its function scope as $1.2F_0$ by considering the importance of this function based on a user survey. The new conceptual scheme contains the above two main functions with function scope 2.2 F_0. For the cost coefficient, we consider the electric blower with a standard cost coefficient C_0, after searching the corresponding cost, cost coefficients of the vacuum cleaner and new conceptual scheme are set as $0.9C_0$ and $1.5C_0$ respectively. Therefore, coefficient values of the electric blower, vacuum cleaner and new conceptual scheme are $1V_0$, $1.33V_0$ and $1.47V_0$, respectively. It is obvious that $1.47V_0 > 1.33Vo > 1V_0$，so it is economical for the new conceptual scheme with two key functions.

4 CONCLUSIONS

Function combination of products can save resources and provide users more functions than single function products. This paper proposed a method of the function combination in product design. Scenario analysis was introduced to the process of combination design. Potential functional units were obtained by analyzing the inner system scenario and super system scenario of the product through a systematic process, which provides a new path for the acquisition of product requirements. The product reconfiguration process was transformed into a complex module compatibility problem to form an abstracted Su-field model. Meanwhile, 76 standard solutions in TRIZ were introduced to solve problems. A case study of design for an innovative electric blower was presented using the proposed method. Comparing with existing methods, the acquisition of valuable functional units for combination is simpler. Expected scenarios of future applications of products are more intuitive, and the process of product reconstructions is simplified. Further work will apply the proposed method to different innovative cases for the improvement. The implementation of the proposed method will be developed into a CAD tool for industrial applications.

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6 ORCID

Limeng Liu, https://orcid.org/0000-0002-9365-1800
Runhua Tan, http://orcid.org/0000-0002-6797-8199
Qingjin Peng, http://orcid.org/0000-0002-9664-5326
Wei Liu, http://orcid.org/0000-0001-6111-4149
Huangao Zhang, http://orcid.org/0000-0001-8945-0056
Jinpu Zhang, http://orcid.org/0000-0002-6813-8466

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