Title:
**Function Combination of Product Reconfiguration based on Scenario Analysis**

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Introduction:
Enterprises must constantly innovate their products to maintain competitive advantages in the market. From the perspective of functional evolution, the evolution from a single functional product to multi-functional product follows an innovation path in line with the market trend [10]. Function combination is a process of combining and optimizing functional elements of a product according to function requirements. The combination can improve the integrity and creativity of the product by integrating different functional characteristics into a single functional carrier [1]. The function combination of products can expand applications of the products and enhance the competitiveness of the products in the market.

In order to assist designers in function combination innovation, there are many studies that have contributed useful methods. Mizoguchi et al [7] established the functional ontology to standardize function combination relationship. Liu et al [5] proposed different functional combinations according to corresponding biomaterial characteristics. Liu et al [4] introduced TRIZ (theory for inventive problem solving) to solve design problems in the function combination. Mcasams et al [6] proposed different products based on similarity, and the similarity analysis of products was used to assist the innovative design of multi-functional products. Zou et al [11] developed a functional design method for variable functions of mechanical products using the function similarity. Although the existing methods have made the progress in key technologies of function combinations, there is a lack of effective methods to search valuable function combination units and implement the product reconfiguration.

Innovation comes from the exploration of different design scenarios [3]. The scenario analysis can help designers to find product changes in the future to make correct decisions and responses to the changes [8]. In this paper, a method of the scenario analysis is proposed to explore product function requirements and decide potential function units. A product system is reconstructed according to relations of functional modules. 76 standard solutions tools in TRIZ are 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.

Main Idea:
Product design is a scenario analogy process to meet function requirements [2]. The scenario 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 researches the 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.

*Function units decision based on* inner system *scenarios*

Existing products provide functions of specific scenarios. Potential functions can be stimulated by changing key scenario elements or expanding scenario related elements. Elements of the product scenario are related environment and user elements. The former is the situation of a product in the action environment including material, energy, space and time. The latter is user factors, including user age, gender, and behavior. Changing or expanding relevant elements and constraints can affect changes of the demand to stimulate the generation of new required functions. Fig. 1 shows the decision process of function units based on the scenario analysis.

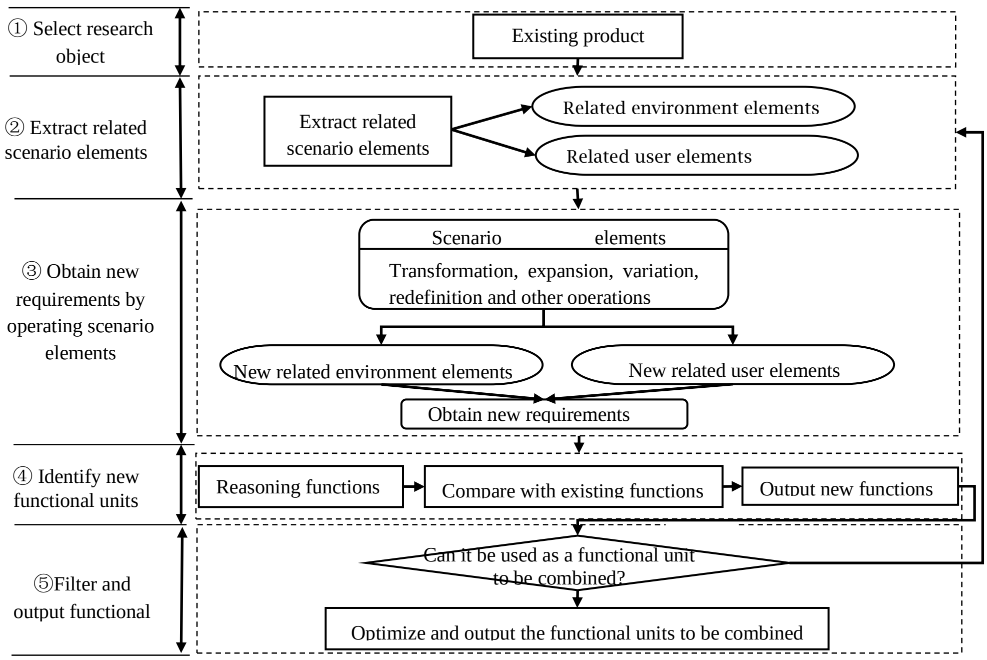


Fig. 1: Decision of function units based on scenario analysis.

*Function units decision based on* super system *scenarios*

Scenarios simulate behaviors of product. Application scopes of the product can be expanded if these behaviors can be mapped into corresponding product functions using the behavior-function scenario analysis chart as shown in Tab. 1.

| Behaviors | Required functions | Function carrier | as a function unit |
|---|---|---|---|
| Behavior $B_1$ | Function $F_1$ | Product prototype or mechanism | Yes\No |
| Behavior $B_2$ | Function $F_2$ | Product Prototype or mechanism | Yes\No |
| … | … | Product Prototype or mechanism | Yes\No |
| Behavior $B_i$ | Function $F_i$ (main function) | Existing product | Yes\No |
| … | … | Product Prototype or mechanism | Yes\No |

Tab. 1: Behavior-function scenario analysis chart.

In the chart, function carriers describe existing products or mechanisms used to complete functions. The behaviors are arranged in the 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 the corresponding columns of behaviors, required functions and function carriers. Designers can decide whether a new function and its carriers matches the existing one to select the appropriate function unit.

*Product reconfiguration based on function combination*

In product function modeling, the product structure can be divided into energy module, power module, execution module, control module and auxiliary module. Among them, the executive module meets the main purpose of the product to complete established functions, while the other modules support the executive module as support modules. In this paper, the existing and proposed products' execution modules are combined to form a function combined product. We build an abstract Su-field model according to relations of existing product's basic support modules and proposed product's execution module. 76 standard solutions in TRIZ [9] are applied to solve corresponding contradictions of function combinations. The main process of product reconfigurations is shown in Fig. 2.

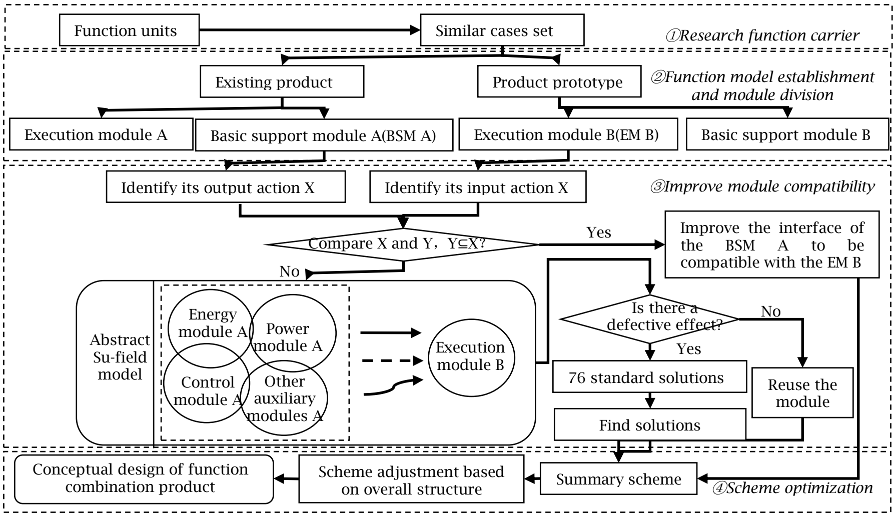


Fig. 2: Product reconfiguration based on relations of product function modules.

*Case study*

The proposed method was applied in a function combination design of the electric blower. The main function of the product is to provide hot air.

1) A scenario is formed based on the function requirement. As the residual hair on the ground is a key scenario element，a new function "collect the hair" is proposed. The hot weather is also added as a key scenario element, the related function is "provide flow wind".

2) A barber shop is selected as the product working place. According to behaviors of customers coming for barber, a barber behavior-function scenario chart is built as shown in Tab. 2.

| Behaviors | Required functions | Function carrier | as a function unit |
|---|---|---|---|
| Wash hair 1 | 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 |

Tab. 2: Barber behavior-function scenario.

Based on Tab. 2, new function units are obtained as "cut hair" and "collect broken hair". Three potential function units can be combined for "collect broken hair", "provide flowing wind" and "cut short hair". Taking "providing warm air" and "collecting and breaking hair" as examples to restructure the product system, processes are as follows.

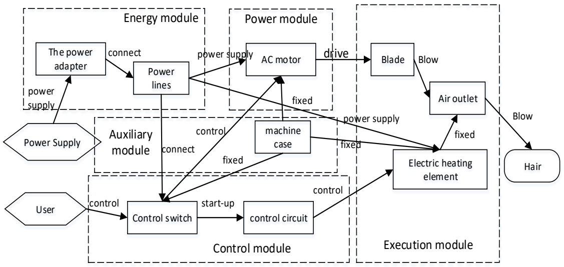


Fig. 3: Function model of Electric blower.

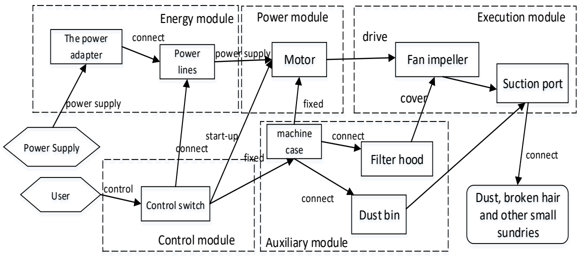


Fig. 4: Function model of vacuum cleaner.

1). Product function models are built as shown in Fig. 3 and Fig. 4.

2). A defective Su-field model is abstracted as shown in Fig. 5.

As the function provided by basic support modules of the hair dryer cannot meet the executive module of the portable vacuum cleaner, a Su-field defective model is abstracted by comparing interactions between basic support modules of the electric blower and execution module of the vacuum cleaner as shown in Fig. 5.

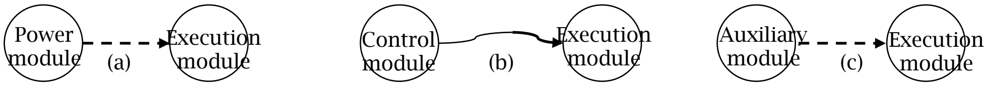


Fig. 5: Abstracted defective Su-field model.

3). Contradiction analysis for conceptual design

Fig. 5(a) shows an incomplete function. According to 76 standard solutions in TRIZ, we select standard solution 1.1.2 to add a fan impeller with the suction function. The 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 Fig. 6 (a) and Fig.6 (b).

The Su-field model shown in Fig. 5 (b) is a harmful function because the electric heating element controlled by the blower control module will affect the dust collection effect. We use the standard solution 1.2.1 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 the electric heating element power supply separately, as shown in Fig. 6(c).

Fig. 5(c) also shows an incomplete function. We use standard solution 1.1.2 to add a dust collection bin and filter cover. We also use standard solution 3.1.2 to improve the shell shape for connecting the dust collection bin and filter cover. As shown in Fig. 6(a), the executive part of the vacuum cleaner is separately constructed as a switchable module.

Therefore, the conceptual design of the new integrated blower and vacuum cleaner is generated as shown in Fig. 6. It is composed of a main body and two conversion heads to perform different functions.

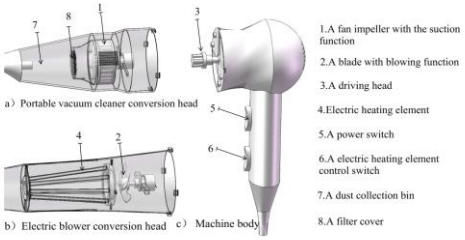


Fig. 6: Conceptual design of new electric blower and dust collector.

Conclusions:
This paper proposed a method of function combinations in product design. Function units were obtained by scenario analyses. The process of product reconfigurations was simplified to improve compatibility of the existing product function support modules and the executive module of new product. 76 standard solutions in TRIZ were introduced to abstract the defective Su-field model. The further work will evaluate the proposed method and solution through the product prototyping and application, to be included in the full paper.

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