Title:
Product Function Redesign based on Extension Theory

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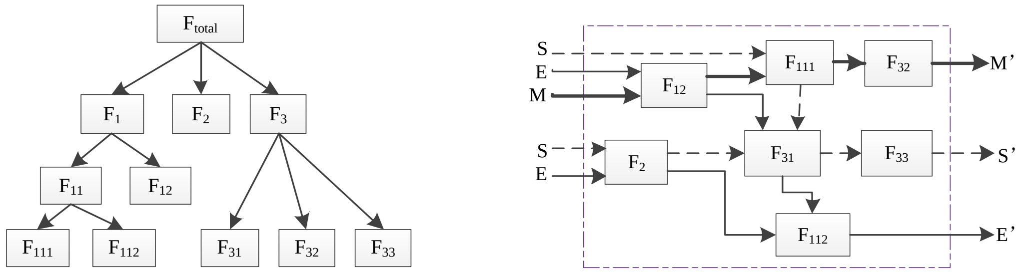
Introduction:
Following the market change to meet user requirements, many enterprises redesign their products using new technologies or processes to adapt changes of the market to improve competitiveness [6]. In the product redesign process, the effective function design is significant for innovative solutions [2-3]. TRIZ (Invention Problem Solving Theory) was proposed by Altshuller based on the analysis of patents. It provides tools to solve problems in a redesign process [8]. Ma et al. [5] proposed a method to identify function components for product redesign based on the failure mode and effects analysis (FMEA). Smith et al. [7] developed an innovative redesign method for new products based on the integration of existing similar products in functions and other aspects. However, most of the existing methods for function design mainly focus on identifying function components to meet customers' requirements. They are subjective and fuzzy in the analysis of functional levels, which is difficult to be used in the redesign process. The extension theory [11] introduced basic-element (BE) to build a formal model with characteristics of formalization of the process, and combination of qualitative and quantitative analyses. It is composed of the extension analysis theory, extension set theory and extension logical [11]. In recent years, the extension theory has been applied to solve uncertainty problems for product redesign. But there is a lack of research that considers quantify functions with the extension theory in the functional level. Meanwhile, function design can stimulate the product innovation in redesign process. In this paper, a method is proposed based on the extension theory for product function redesign. For a target product to be redesigned, a hierarchal function model of the target product is first formed using the function analysis. Degree of the function importance is then determined by applying the triangular fuzzy number (TFN) [4]. Difficult function unit (DFU) and high important degree function (HIDF) are decided according customers' requirements (CRs) and ranking of function importance degrees. A function redesign model is developed based on the extension theory and TRIZ tools to apply DFU and HIDF. Feasibility of the proposed method is verified in redesign of an ultrasonic-based measurement device of the paper thickness.

Main Ideas:
Redesign methods are generally applied for product innovation to reduce development cycles and costs [1]. This paper aims at identifying HIDF using TFN and implementing identified functions using extension transformation and TRIZ tools. A target product can be identified according to internal and external

changing needs of the product. For the target product redesign in functional level, a hierarchal function model of the target product is built based on the function analysis as shown in Fig. 1, which is prepared for degrees of the function importance.

DFUs can be identified based on the structure and implementation of the product. Degrees of the function importance are decided by introducing TFN in the hierarchal function model. For a product with main function units *n,* based on pair-wise comparisons of their importance, a triangular fuzzy number matrix (TFNM) can be formed as shown in Eqn. (1).



(a) Functional tree (b) Function structure model

Fig. 1: Hierarchal function modeling of the target product.

$$F = \begin{bmatrix} f_{11} & \dots & f_{1n} \\ \dots & f_{ij} & \dots \\ f_{n1} & \dots & f_{nn} \end{bmatrix} = \begin{bmatrix} (f_{11}^L, f_{11}^M, f_{11}^U) & \dots & (f_{1n}^L, f_{1n}^M, f_{1n}^U) \\ \dots & (f_{ij}^L, f_{ij}^M, f_{ij}^U) & \dots \\ (f_{n1}^L, f_{n1}^M, f_{n1}^U) & \dots & (f_{nn}^L, f_{nn}^M, f_{nn}^U) \end{bmatrix} \quad (1)$$

Where f_{ij} is a fuzzy value of the function importance compared between i^{th} and j^{th}; f_{ij}^L and f_{ij}^U are lower and upper bounds of the importance, and f_{ij}^M is the most probable importance. $f_{ij}^L + f_{ji}^U = f_{ij}^M + f_{ji}^M = f_{ij}^U + f_{ji}^L = 1, f_{ii}^L = f_{ii}^M = f_{ii}^U = 0.5, f_{ij}^L \le f_{ij}^M \le f_{ij}^U; \; i, j = 1,2, \dots n$

TFNM is then processed by the importance ranking management software (KC V1.0) [4] to decide degrees of the function importance using fuzzy ordered weighted averaging (FOWA) operators [4] such as $D = (d_1, d_2, \dots, d_n)^T$. The ranking of function importance degrees is used in finding HIDF. DFUs and HIDFs can then be represented in a form of the functional basic-element as $B_F = (O, c, v)$. Where O is DFU or HIDF, c is the functional characteristic, and v is the value of O concerning c. We can obtain function extension set B_E by applying the extension analysis theory as shown in Fig. 2.

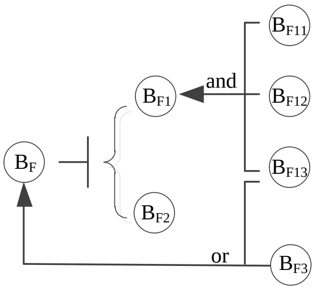


Fig. 2: Extension analysis of functional basic-element.

Fig. 2 forms several new routes to guide design searching for functional basic-element B_F. However, it only provides some possibilities for generating ideas by the extension analysis theory. In order to find innovative solutions, an extension transformation is introduced to B_F. There are five basic extension transformations including displacement, addition or deletion, expansion ($0<\alpha<1$, T is reduction), decomposition, and copy, as shown in Eqn. (2).

TRIZ tools are then used to solve contradictions in a new way of the function level. The innovative solution can be developed by a priority degree evaluation. Therefore, the product function redesign process model can be built using the extension theory as shown in Figure 3.

$$TB_F = \begin{cases} B_{Fi} & T \in displacement \\ B_F \pm B_{Fi} & T \in \text{addition or deletion} \\ \alpha B_F & \alpha > 0, T \in \text{expansion} \\ \{B_{F1}, B_{F2}, \ldots\} & T \in \text{decomposition} \\ \{B_F, B_F^*\} & T \in \text{copy} \end{cases} \tag{2}$$

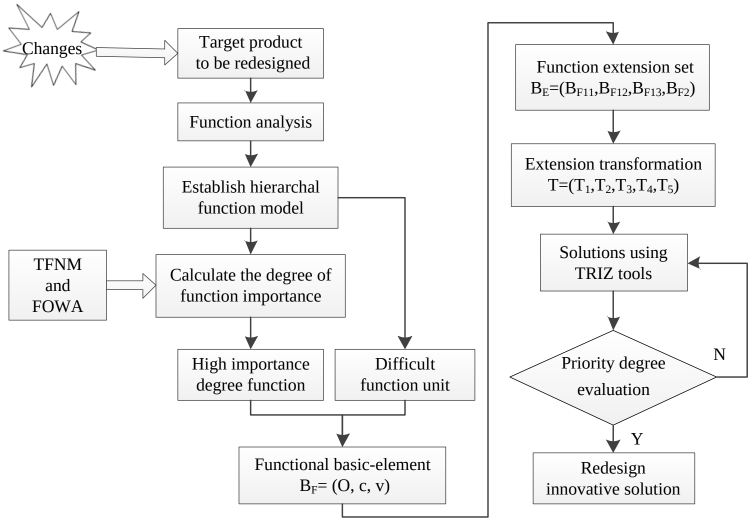


Fig. 3: Product function redesign process based on the extension theory.

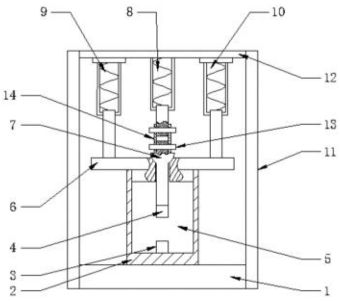
Case Study

Fig. 4 shows an ultrasonic-based measurement device of the paper thickness [9] (Hereinafter referred to as "measurement device"). In order to improve the measurement accuracy, water is used to replace gas as ultrasonic medium. However, the measurement accuracy is affected. In addition, more energy is consumed because of the large-sized tank body.

According to the proposed function analysis, a hierarchal function model of the measurement device was built to search function units as shown in Fig. 5. Fig. 5 (a) is the functional tree of measurement device, Fig. 5 (b) shows the function structure model of the measurement device. There are eight function units identified, including F_1-transmit ultrasonic, F_2-drive electromagnet, F_3-record time, F_4-process data, F_5-display information, F_6-receive ultrasonic, F_7-press papers, and F_8-loose papers.

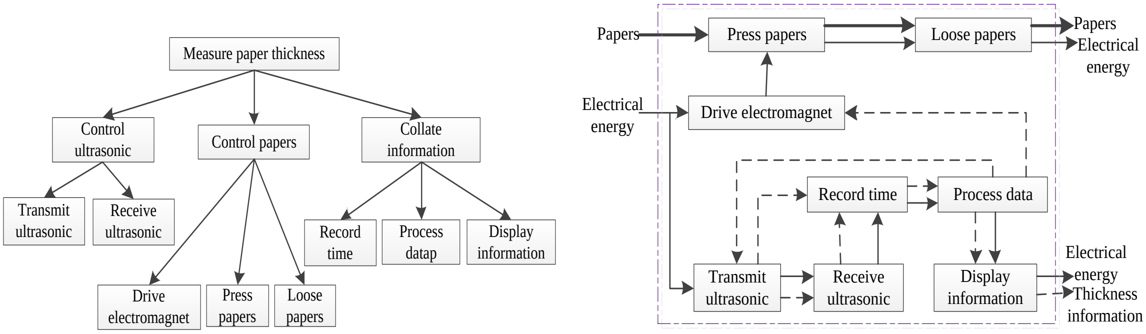
TFNM was then formed as $F = [f_{ij}^L, f_{ij}^M, f_{ij}^U]_{8\times 8}$ using Eqn. (1). It is processed by the importance ranking management software (KC V1.0) [4] to decide degrees of the function importance using FOWA operators [4] as D= (d_{F1}, d_{F2}, d_{F3}, d_{F4}, d_{F5}, d_{F6}, d_{F7}, d_{F8}) = (0.117, 0.161, 0.106, 0.117, 0.082, 0.171, 0.123, 0.123) using FOWA operators. F6 was identified as the most important functions. F6 was identified as the most important function. Therefore, F6 was the HIDF considering measurement accuracy., and represented in a form of the functional basic-element B_{FF6} as shown in Fig. 6.

In addition, a function extension set B_E was obtained using methods of the divergent tree for the extension analysis of function F_6 as shown in Fig. 6. Where $B_E = (B_{F1}, B_{F2}, B_{F3})$. According to B_{FF6} and B_E, functional basic-element B_{FF6} can be replaced with B_{F2} by applying the extension transformation Eqn. (2)



1- Paper holder, 2-tank body, 3- transmitting probe,
4- receiving probe, 5-medium, 6- top cover of tank, 7-halfsphere valve, 8-electromagnet I,
9-electromagnet II, 10-electromagnet III, 11-support frame,12-upper frame, 13-Fixed pin, 14-casing pipe

Fig. 4: Structure of the measurement device [9].



(a) Functional tree of measurement device (b) Function structure model of measurement device

Fig. 5: Hierarchal function modeling of measurement device.

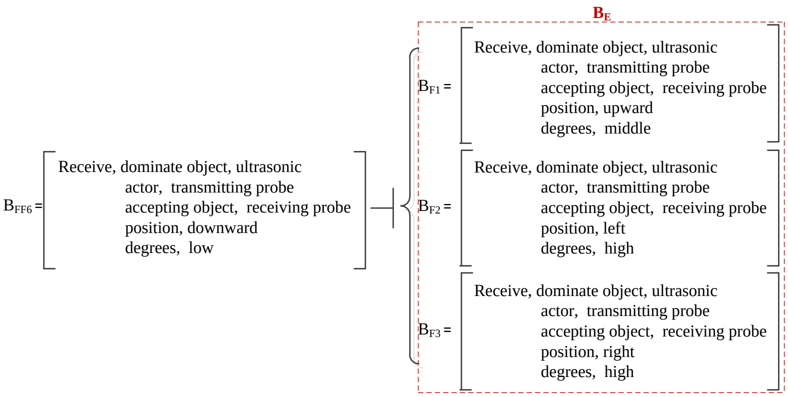
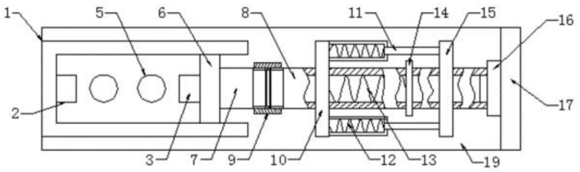


Fig. 6: The extension analysis of function f_6.

as $TB_{FF6} = B_{F2} = B_{F3}, T \in displacement$ .Solutions were achieved by applying TRIZ tools based on a new route in the functional level as shown in Fig. 7. The measuring surface is separated from the tank body to reduce the driving weight. Meanwhile, the receiving probe is placed horizontally with the piston to solve the interference of medium bubble. Therefore, the redesign solution greatly improves measurement accuracy, reduces costs and saves energy.



1-tank body, 2-transmitting probe, 3-receiving probe, 4-medium, 5-breathing pipe, 6-piston, 7-left cylindrical tube, 8-right cylindrical tube, 9-casing pipe, 10-fixed pin, 11-upper electromagnet, 12-lower electromagnet, 13-spring, 14-locking pin, 15-connection pin, 16- measuring surface, 17-paper-holded surface,18-floor

Fig. 7: Redesign solution of the measurement device [10].

Conclusions:

A function redesign method was proposed for the product innovation based on the extension theory. The triangular fuzzy number was applied to decide the function importance for an extension function decision-making process. New routes were found by the extension transformation of the functional basic-element. The method is verified in an innovative redesign of the an ultrasonic-based measurement device of the paper thickness.

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