Function acquisition for adaptable-function product design based on functional and behavioral information modeling

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One of the advantages of the adaptable-function product is that it can achieve multiple functions with some shared parts, hence it is structurally compact. To ensure the market success of this kind of product, it is of great importance that the adaptable functions to be delivered by such kind of product are not only suited to the structural characteristics of the product, but also can make the product easy for designing and manufacturing, as well as are convenient for use and service. Until now there has been literally no research that is specifically focused on how to help the designer acquire such functions. By studying the characteristics of the adaptable-function product, this paper proposes to acquire the adaptable functions by exploiting the "input-output flow" type of representation method to model the product function and behavior information, whereby the energy flows and material flows are properly processed. The effectiveness of the proposed method is demonstrated by the adaptable-function design process of an electric metal cutting machine.

Introduction

The adaptable-function products are a specific type of products that can achieve multiple functions by changing the structure of the system [1]. There are two aspects of research relevant to the adaptable-function product design: the adaptable design and the reconfigurable design. The adaptable design [2-4] aims to redesign the product by applying various modern design methods and techniques, so as to meet the needs of the market quickly and meet the needs of customs. The reconfigurable design focuses on reconfiguration of system resources to achieve the new design requirements [5, 6]. The reconfigurable design changes system performance by replacing different modules or similar components to meet different application needs.

The adaptable-function products are nowadays getting more popular among customers, because they help enhance the awareness of environmental protection and energy conservation. Compared with traditional single-function products, the adaptable-function products not only have many functions and are resource saving, but also are easy to upgrade [1]. At present, most researches of the adaptable-function product are focused on its product characteristics and conceptual design process, as well as related design strategies and methods. For example, based on FBS model, Yang et al [7] have done some adaptable-function redesign research with the concept of behavior chain, and a system framework supporting adaptable-function redesign was also proposed. After studying the identification of the shared parts and the interface solution of mechanical products, Wang et al [8] proposed two criteria and two kinds of methods for interface solution relevant to the adaptable-function product design.

Even though there has been some work on the adaptable-function product design, there has been literally no work on how to acquire the adaptable functions. This is equally important because only with the adaptable functions known, can the designers have a clear objective in designing new adaptable-function product, or redesign existing product towards being functionally adaptable. Besides, the adaptable functions must not only meet the needs of customers, but also facilitate the design process, as well as the future manufacturing process. To address this problem, this paper attempts to study the characteristics of adaptable-function products, and based on this, to investigate the methodology for the acquisition of suitable adaptable functions.

1. Characteristic analysis of the adaptable-function product

To facilitate elaboration, an adaptable-function micro tillage machine and an adaptable-function power drill are taking as two examples in the following study.

1.1 Analysis of the adaptable-function micro tillage machine

Fig 1 shows the adaptable-function micro tillage machine.

Fig 1. The adaptable-function micro tillage machine

This is a typical adaptable-function product used for agriculture, where multiple functions are often necessary, and due to seasonal reason, different functions may be used at different times. Such a product is of great usefulness to the farmers, as it can deliver multiple functions with some share parts, thus saving their investment in farming tools.

It is noticed that, when the shared parts used for different functions are connected with the rotary cutter and the wheel, respectively, the function of both cultivating land and transportation can be realized in turn. The energy flows in the process of cultivating land and transportation are analyzed in Fig 2.

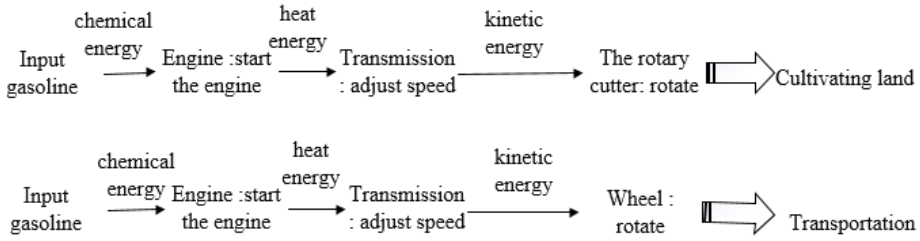

Fig 2. Energy flows according to functional modeling

As can be seen, the adaptable-function micro tillage machine achieves both functions with the same energy flow, where two functions are achieved by connecting the shared parts with two different executing structures. Similar study of more functions will reveal that, the adaptable-function micro tillage machine achieves a variety of functions with the same energy flow and the same executing behavior, only the executing structures are different.

1.2 Analysis of the adaptable-function power drill

The adaptable-function power drill achieves multiple functions through different executing behaviors. Its structure and behavior flow are more complex compare with those of the micro tillage machine. Fig 3 shows an adaptable-function power drill, which can be used for drill (power drill), impact (electric pick), both impact and drill (power hammer), etc.

Fig 3. The adaptable-function power drill

The adaptable-function power drill can perform impacting, drilling, impacting and drilling with different executing structures and different executing behaviors. The corresponding energy flows of all functions are shown in Fig 4.

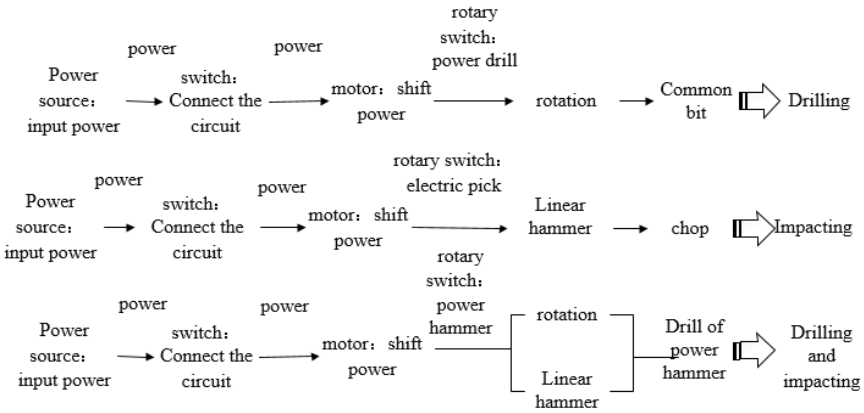

Fig 4. The energy flows of the adaptable-function power drill

As shown in Fig 4, these three functions have the same energy flow, but different executing behaviors. Such products can overcome the weakness of those products with single behavior, in that it can provide more functions for the users.

Through the above analysis, it can be seen that the adaptable-function product can achieve multiple functions by changing the executing behaviors with the same energy flow; or with the same energy flow and the same executing behavior, yet with the changed executing structures. Furthermore, multiple functions can also be achieved by changing the energy flow. With this insight, we propose the following method to acquire the adaptable functions with the help of functional and behavioral information modeling.

2. Acquiring the adaptable functions

Function acquisition is the initiating work for redesigning and upgrading of an existing product, no matter whether it is an adaptable-function product or not. In the previous work of our research group [9, 10], we have studied the functional upgrading redesign of the adaptable-function product based on the principle of case retrieval. That work, however, did not consider how the adaptable functions are to be acquired. To address this problem, it is necessary to model the function and the behavior information of the existing products, and then acquire new functions by means of certain information processing methods (such as analogy, reasoning, changing, etc).

Considering the fact that the expression of the "input-output flow" is more suitable for the design problems with obvious energy flow, material flow and signal flow [8], and the adaptable-function products usually possess such characteristic, we adopt the input-output flow scheme to carry out function and behavior information modeling. On this basis, new functions can be acquired through the following operations.

2.1 Acquiring adaptable functions by changing the material flow

(1) Acquiring new functions by extending material flow

For the product that delivers its function by material flow, it is possible to consider extend the existing material flow so as to achieve new function. For example, the material transformation process of wheat is shown in Fig 5, the function of threshing wheat can be acquired through extending the material flow of wheat to clean grain. By this means, through the adaptable-function redesigning process, the product of both harvesting function and threshing function can be designed.

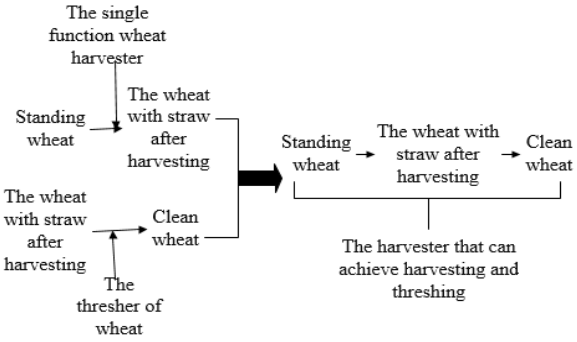

Fig 5. Acquiring function through extending the material flow of wheat

(2) Acquiring new functions by changing material flow with the same energy flow and signal flow

In the expression of the "input-output flow" of the function, it expresses a number of similar functions when the material flows are different with the same energy flow and signal flow. As shown in Fig 6, where "e" represents energy, "s" represents signal, "m" represents material.

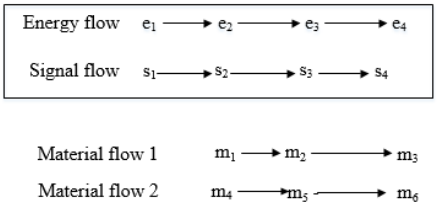

Fig 6. Different material flow with same energy flow and signal flow

Fig 6 illustrates two functions with the same energy flow and signal flow, yet different material flows, i.e. material flow 1 and material flow 2. Even though the two functions are different, they are also similar, due to the characteristics of same energy flow and same material flow. As such, new adaptable function can be acquired for an existing product by changing its material flow.

2.2 Acquiring adaptable function by changing the energy flow

(1) Acquiring new functions by extending energy flow

Fig 7. The fitness and washing machine

By analyzing the energy flow of a product, and study the energy characteristics of the end energy of the flow, another function may be acquired by converting the end energy into other form or other energy. For example, the fitness bike is normally designed as connecting the wheel with the pedal. Considering fact that the kinetic energy generated by the wheel is not fully utilized, resulting in some energy wasting, we may convert the wheel rotation into the rolling energy of the washing machine drum. As such, the function of both washing clothing and fitness can be achieved, resulting in a new design as shown in Fig. 7 [9].

(2) Acquiring new functions by adding energy flow

Different forms of energy can be used to achieve different functions, and different executing structures with the same form of energy may also achieve different functions. The same initial energy can be converted to the energy of different structures. In this way, new functions can be acquired through adding different energy flows. Take the tractor as an example, as is shown in Fig 8.

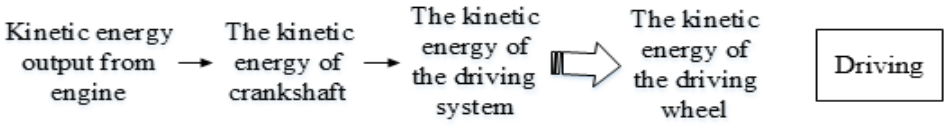

Fig 8. The energy flow of a tractor

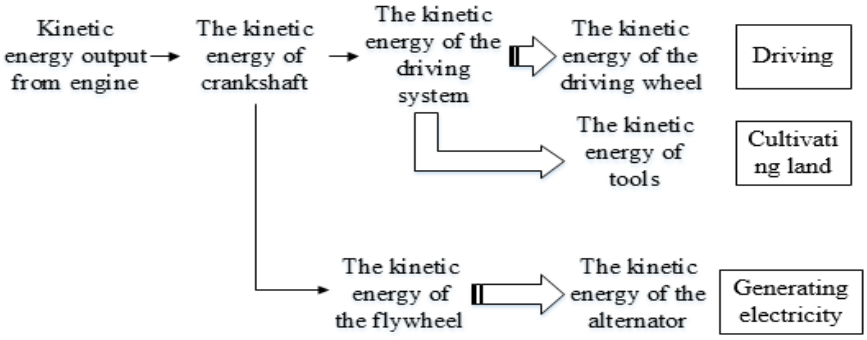

Fig 9. Adding energy flow to acquire new functions of the tractor

As shown in Fig 9, the tractor can achieve the function of cultivating land and generating electricity by adding other some energy flows.

3. Case study

To illustrate as well as demonstrate the above function acquisition method, this section takes an electric metal cutting machine for case study. This is a multiple-function and also handy tool used for quick metal cutting. It is assumed that designers and customers want to redesign it, so that it can achieve more functions to sustain competitiveness in the market place.

Fig 10. The electric metal cutting machine

After an analysis of this product, we can acquire the adaptable functions by applying the above adaptable function acquisition method. First, we can acquire the functions of grinding metal and polishing metal by the method of acquiring adaptable functions from extending material. Second, in view of the fact that we often need to cut different materials, such as wood and stone, we can acquire the functions of cutting wood (or stone), grinding wood (or stone), polishing wood (or stone), and so on. With these acquired functions, we can proceed to the next step of design process, i.e., to develop a new adaptable-function product with all these functions.

Conclusion

By investigating the characteristics of the adaptable-function product, we put forward some methods to help designers acquire suitable adaptable functions, so that the designers can further their product development towards implementation of the adaptable-function product capable of delivering such functions. With the proposed methods, designers can acquire the functions that are both suited to the structural characteristics of the product and are easy for its designing and manufacturing. Designers can go on the next stage of the redesigning process after acquiring these functions. The effectiveness of the proposed methods has been demonstrated by a case study of an electric metal cutting machine. Further work is necessary in

addressing the problem of how to evaluate the acquired adaptable functions, so as to help the designers select the most suitable ones for further product development.

Acknowledgement

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