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Open interface design for product personalization

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ABSTRACT

Open interfaces can improve the product personalization using product functional modules developed by third party vendors. They also support the product update through the module upgrading or replacement during the product lifespan. Characteristics of open interfaces are firstly investigated by the comparison with traditional mechanical interfaces. Methods are then introduced for the design, evaluation and operation of open interfaces. An open interface of the electric vehicle is proposed for the connection of different battery packs to verify the feasibility of proposed methods. Novelty of the research is the improved open interface for personalized products.

1. Introduction

Personalization is an emerging trend in product development to meet diversified customers' requirements [1,2]. It is proposed to apply personalized modules in a product for different users. For a personalized product using functional modules developed by customers or the third party vendors, the product should have open interfaces to adopt the different modules. In a traditional product, product interfaces are usually designed to connect pre-defined functional modules in the product [3]. Personalized modules from different sources are not allowed to be added onto the product. For example, an automobile interface to connect the engine is a traditional interface as only pre-defined engines are allowed to connect to the car platform through the interface. For the massive product personalization, product interfaces should be open to enable personalized modules from different sources adding on an original product. For example, an excavator interface to connect the front execution device is an open interface as different functional devices (e.g. hammer, digger, bucket, etc.) from various producers can be connected to the excavator through the interface.

Product development must simultaneously consider different requirements in the function, cost, quality, and life cycle. Methods and tools for the product innovation have been reported in the CIRP community [4–6]. An open interface can facilitate product modules reusing, upgrading and replacing for product sustainability in addition to the personalization, customization and cost-effectiveness.

An interface can be defined as a common port to connect or combine different functional units in a product for energy exchange, transformation of motion, force or information to perform specific functions through linked functional units. Based on technical specifications, interfaces can be classified into mechanical, electrical, software interfaces, etc. Mechanical interfaces are used to build connections of physical components of a product using connectors such as planes, fasteners and pins. [7].

It was found that the existing research mainly considers relations of the interface function and behavior in a product. Analytical models are used to abstract interface details from the physical form. In addition, there is a trend to search parameters of interface properties for the evaluation or improvement of interfaces. Based on our previous work in the interface research [8], this paper introduces an approach to design mechanical open interfaces for product personalization. A comparison between traditional and open interfaces is shown in Table 1. An open interface of the mechanical product has features of the public accessibility, easy assembly and disassembly, and adaptability as shown in Fig. 1.

2. Methods of open interface design and improvement

A method is proposed for the open interface design using the module function correlation matrix, House of Quality (HoQ), and measures of the interface efficiency as shown in Fig. 2. The method searches feasible mechanical open interfaces for required connections of product modules.

A functional correlation matrix is established based on module types planned in the product modular design stage. Connections of modules are identified in the correlation matrix for interfaces planning. Design factors that affect the open interface are summarized in the HoQ. Measures of the interface efficiency consider the module structure, interface connection and module handling in the interface operation based on guides of design for manufacturing, design for assembly, and design for disassembly. Criteria for the efficiency of interfaces (EoI) are proposed based on geometrical and operational factors of the open interface as

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Table 1
Comparisons of traditional and open interfaces in mechanical products.

	Traditional interface	Open interface
Definition	Interface used to connect modules specified in the interface design process An example: an automobile interface to connect the engine	Interface used to connect platform with unknown modules that can be provided by the third party vendors An example: an excavator interface to connect front execution devices
Characteristic	Closeness; not for the user assembly and disassembly Lack of adaptability; lack of standardization	Openness; easy for user assembly and disassembly Adaptability; standardization
Implication	Closed innovations for both product and technology Closed business model; lack of the product personalization	Potential open innovations for both product and technology Open business model; personalized functions
Pros	Easy to predict influence of add-on modules on product performance Easy to control the product quality and reliability	Better product variety and flexibility Better adaptability, sustainability, upgradeability, and extendibility
Cons	Lack of the product variety and flexibility Lack of adaptability, sustainability, upgradability, and extendibility	Hard to predict influence of add-on modules on product performance Hard to control the product quality and reliability

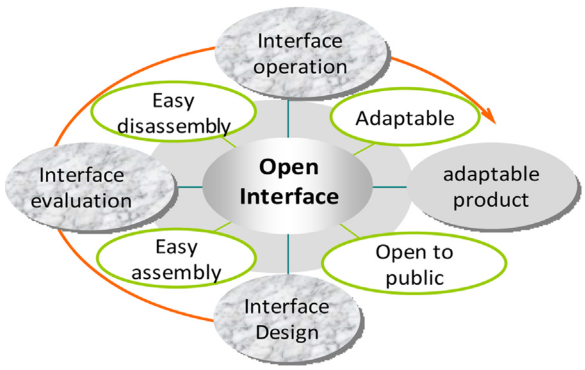

Fig. 1. Characteristics of open interfaces.

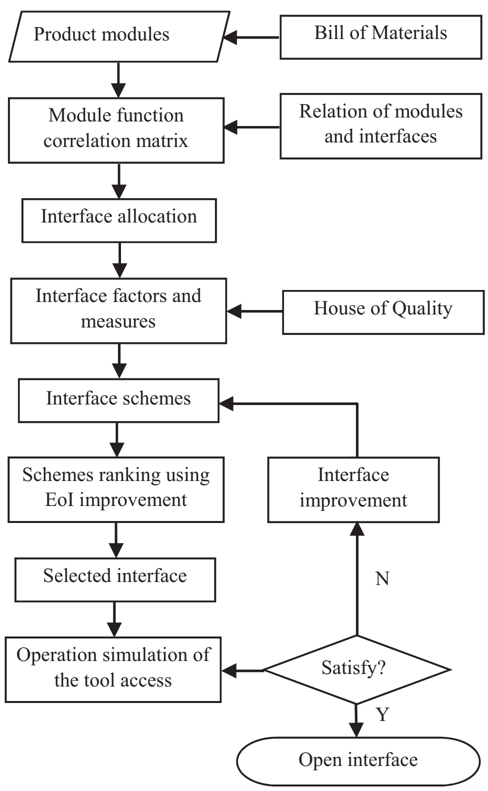

Fig. 2. Flow chart of the open interface design.

follows.

$$\text{EoI} = f(I_p, I_c, P_i, I_h, O_a) \quad (1)$$

where geometrical factors include the shape, size, and weight of the interface profile (I_p), and the number, size, weight of interface connectors (I_c). Operational factors consider interface operations for the ease of positioning (P_i) and handling (I_h), and accessibility (O_a) for the ease of assembly, disassembly and tool applications in the operation of fasteners. Numerical values of these factors are assigned by weighting factors (w_i) based on their importance in the interface application, including function modules connected, connectors used, complexity in geometry and operations, operation accessibility, and tools used in interface operations. For commonly used various fasteners such as the bolt, screw, pin, taper, key way, and spline fit, their weighting factors are assigned considering the number of parts connected and tools used in the operation. Solutions are ranked in the HoQ to search the optimal interface. The detail design of interfaces is then conducted based on the selected interface scheme.

For the tool accessibility during the interface operation, a method is proposed by combining a box-based method and the global accessibility cone with depth (GAC^d) [6]. The accessible analysis checks interfaces considering operational space constraints and accessibility of operational tools.

Tools are classified into two types based on a factor that the tool's axis is coincident or not with its rotation axis during the tool operation. GAC^d is combined with the box-based representation to simplify the analysis of the complex structure of the interface accessibility for tool operations. The proposed tool accessibility reasoning method checks parameterized tool operations using approximates obstacles of the interface. Spatial directions of the tool access to a fastener are represented in a global coordinate system with 360×180 pixels projected to a 2D space, which simplifies the complex process of collision detections using a relative easy analysis method.

Therefore, a comprehensive process of the open interface design includes following five steps: the interface allocation based on the product bill of materials; module relation identifications in the correlation matrix; formation of the decision matrix using the HoQ; selection of the interface based on ranking of alternatives; and operation simulation for the tool accessible analysis. An open interface can be finally formed in the interface detail design.

The reliability is ensured in every step of the process. The interface location and relations must meet the need of module connections. The module selection, formation and operation simulation check the satisfaction of the interface application in the personalized product. As different types of modules are replaced or upgraded with different frequencies and probabilities during the product lifespan, open interfaces are considered differently. We consider the interface adaptability for current and future needs to decide performance measures in manufacturing, assembling, operating, and cost of the interface.

3. A case study

Battery packs are critical in the development of electric vehicles. Specifications of an electric vehicle including the price,

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