Title:
Adaptable Interface Design for Open-architecture Product

Authors:
Chonglin Hu, 11clhu1@stu.edu.cn, Shantou University
Qingjin Peng, Qingjin.Peng@umanitoba.ca, University of Manitoba
Peihua Gu, peihuagu@stu.edu.cn, Shantou University

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Introduction:
Personalized products require the changeability of product functions and users' involvement in the product design and implementation. An open-architecture product (OAP) allows the change of product functions by adding or replacing functional modules in its original structure. The OAP consists of three types of functional modules that are product common modules, customized modules, and personalized modules [1]. Interfaces are key elements in OAPs to ensure the module updatability. There is limited research in the interface of OAPs. Most of the existing research provides only strategies or guidelines for the interface design, or descriptive methods for the design of interfaces. Hu et al proposed a method of the interface evaluation using interface efficacy to guide the interface improvement for the easy assembly and disassembly of product modules, but the interface should be considered in the product design with constraints of the product structure and details [2]. This research proposes a method for the adaptable interface design of OAPs. Interface types and design requirements are defined according to the type of modules using a functional description method of interfaces. Interface design schemes are established based on interface functions and morphology matrices. A fuzzy analytical hierarchy process (FAHP) is applied to rank the design solutions based on the design requirement of interface types and evaluation measures. An optimal design scheme is planned based on the total score of ranking for the detail design of interfaces. Industrial painting machines are used for the body painting of toys made of plastic or metals. The machine function adjustment is commonly required in the operation for different colors, shapes, or sizes when different toys are produced. An OAP is proposed for the painting machine to meet the functional change requirements effectively. One of the important elements in the open-architecture painting machine is the adaptable interface. This paper discusses the interface design of the machine.

Main Idea:
Interfaces are designed based on product modules and the module types for the need of OAPs. A functional relation matrix can be formed based on the function transformation among product modules as shown in Fig. 1, where C indicates the connection, S shows the transmission of signals, M is the material flow, and P is for the energy transformation. Three types of interfaces can be defined based on three types of modules in OAPs, they are common module interfaces, customized module interfaces, and personalized module interfaces. As common modules are installed by manufacturers in the factory, there is no need to consider much for their interfaces. Similarly, the customized modules are designed and made by manufacturers; their installations are completed when the machines are shipped to users. The personalized modules are flexible for users used in their working place. Therefore, the interface of personalized modules is a key factor for the success of OAPs. Interface schemes can be planned based on module functions and the morphological matrix. The schemes are then evaluated for the optimal solution using the FAHP method [3]. Based on the OAP requirement, the

interface design considers adaptability, workability, assemblability and economic ability. Where the adaptability can be divided into the adaptable ability for existing and predicted needs; the workability includes interface stability, reliability, loading capacity and adjustability; the assemblability is to simplify the structure complexity, assembly difficulty, and the skill requirement for operators; the economic solution will reduce the manufacturing difficulty, sensitivity of manufacturing errors, function redundancy, and energy consumption.

Considering the variety and uncertainty of design parameters, a fuzzy decision-making matrix is constructed using triangle fuzzy numbers based on requirements of different interfaces. Weights and ranks of different designs can be obtained for scoring the evaluation to decide the optimal design in the detail design of interfaces. For the design evaluation using the FAHP method, the weight of evaluation indexes is calculated based on the fuzzy judgment matrix using triangular fuzzy numbers [4]. Comprehensive fuzzy values w_i of the evaluation index are obtained using Eqn. (1). The probability matrix $P=(p_{ij})_{n\times n}$ is formed by comparing w_i pairwise using Eqn. (2). The weight of evaluation indexes q_i can then be calculated using Eqn. (3).

$$w_i = \frac{\sum_{j=1}^{n} a_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}} = \frac{\sum_{j=1}^{n} (a_{lij}, a_{mij}, a_{uij})}{\sum_{i=1}^{n}\sum_{j=1}^{n} (a_{lij}, a_{mij}, a_{uij})} = \frac{\left(\sum_{j=1}^{n} a_{lij}, \sum_{j=1}^{n} a_{mij}, \sum_{j=1}^{n} a_{uij}\right)}{\left(\sum_{i=1}^{n}\sum_{j=1}^{n} a_{lij}, \sum_{i=1}^{n}\sum_{j=1}^{n} a_{mij}, \sum_{i=1}^{n}\sum_{j=1}^{n} a_{uij}\right)} = \left(\frac{\sum_{j=1}^{n} a_{lij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{lij}}, \frac{\sum_{j=1}^{n} a_{mij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{mij}}, \frac{\sum_{j=1}^{n} a_{uij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{uij}}\right), i \in n \tag{1}$$

$$p(w_i \geq w_j) = \lambda \max\left\{1-\max\left(\frac{b_m-a_l}{a_m-a_l+b_m-b_l}, 0\right), 0\right\} + (1-\lambda) \max\left\{1-\max\left(\frac{b_m-a_l}{a_m-a_l+b_m-b_l}, 0\right), 0\right\} \tag{2}$$

$$q_i = \frac{1}{n}\left(\sum_{j=1}^{n} p_{ij} + 1 - \frac{n}{2}\right) \tag{3}$$

Where, $w_i=(a_l, a_m, a_u)$, $w_j=(b_l, b_m, b_u)$, $\lambda\in[0,1]$, and $\lambda=0.5$, $p_{ij}=p(w_i\geq w_j)$ is called probability of $w_i\geq w_j$.

Weights for different types of interfaces are then obtained as $q_G=\{q_{GCi}\}$, $q_C=\{q_{CCi}\}$, $q_P=\{q_{PCi}\}$, for the evaluation of common module interfaces, customized module interfaces, and personalized module interfaces, respectively. Where i= 1, 2, … , 13 used to represent the common adaptability, predicted adaptability, stability, reliability, loading ability, adjustability, structure complexity, assemblablity, required skill of operators, manufacturability, sensitivity of manufacturing errors, function redundancy, and energy consumption, respectively.

Fig. 2 shows a design solution of the interface for the painting machine using the proposed method. The interface is used for the quick assembly and disassembly of personalized modules in users' environments to meet different functions of the machine operation. The interface has the commonality to effectively meet the personalized need.

<table>
<tr><td>Module</td><td colspan="2">M1</td><td colspan="2">M2</td></tr>
<tr><td rowspan="2">M1</td><td colspan="2" rowspan="2">1</td><td>C</td><td>S</td></tr>
<tr><td>M</td><td>P</td></tr>
<tr><td rowspan="2">M2</td><td>C</td><td>S</td><td colspan="2" rowspan="2">1</td></tr>
<tr><td>M</td><td>P</td></tr>
</table>

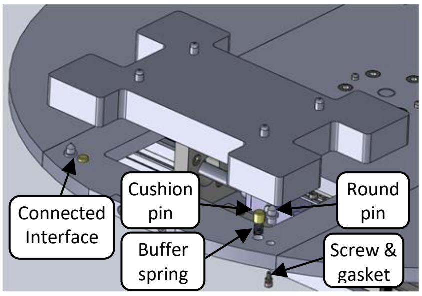

Fig. 1: Functional relation matrix of modules. Fig. 2: Partial view of interface M3-M11.

<u>Conclusions:</u>

Interfaces play the important role in OAPs. Adaptable interfaces support personalized modules to meet changing requirements of product functions. This research proposed a method for the design of adaptable interfaces to meet the requirement of OAPs. The method has been used in the interface design of a painting machine with features of the commonality and easy operation for personalized demands in the machine application. Further research is the sensitivity analysis of the proposed method applying to different products for the method improvement.

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