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Modular design to support green life-cycle engineering

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Abstract

The severe competition in the market has driven enterprises to produce a wider variety of products to meet consumers' needs. However, frequent variation of product specifications causes the assembly and disassembly of components and modules to become more and more complicated. As a result, the issue of product modular design is a problem worthy of concern. In this study, engineering attributes were added to the liaison graph model for the evaluation of part connections. The engineering attributes added, including contact type, combination type, tool type, and accessed direction, serve to offer designers criteria for evaluating the component liaison intensity during the design stage. A grouping genetic algorithm (GGA) is then employed for clustering the components and crossover mechanisms are modified according to the need of modular design. Furthermore, a reasonable green modular design evaluation is conducted using the green material cost analysis. According to the results, adjusted design proposals are suggested and materials that cause less pollution are recommended to replace the components with pollution values higher than those in the module. Finally, the authors use Borland C++ 6.0 to evaluate the system and clustering method. To illustrate the methodology proposed in this study, a table lamp is offered as an example.

Keywords: Modular design; Green life-cycle engineering; Grouping genetic algorithm; Liaison intensity; Green analysis

1. Introduction

Not until recent years have people realized the importance of environmental protection. People pay more attention to the environment they are living in and the way people deal with the limited resources. Among resource disposal methods, recycling and garbage classification are two methods widely applied. These ways, however, are passive methods in the launch, usage and damage of products. Moreover, fierce market competition is shortening the product life cycle and the passive resource recycling approach can no longer cope with the ever-increasing burden current products have on the environment. Therefore, it is important to maximize the usage percentage of resources and minimize the damage to the environment in the early product design stage. This kind of more aggressive design tendency is referred to as green life-cycle engineering design (Otto & Wood, 2001; Tseng & Chen, 2004).

The so-called product life cycle refers to the total amount of time from material, manufacturing, assembly, consumer use, and final disposal or recycle of a product, and green life cycle is mainly determined by the last two stages, product use, disposal or recycle. While the use of a product will affect its life span, the disposal and recycle of a product will definitely affect the environment and the resource availability. To prolong the product's life cycle and to make the most of resources, the end of the product life cycle does not imply the disposal of the components. Instead, we need to solve the problem from the root of the enterprise activities, especially from the R&D of new products (Tseng & Chen, 2004). Many researchers have explored the issue from different points of view, such as design for environment (DFE), design for recycling (DFR), and design for disassembly (DFD) (Güngör

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& Gupta, 1999; Lambert, 2003). Due to the fact that well-designed modular structures can improve product life-cycle activities, modularity plays a more important role than the whole product life-cycle approach. For example, not only will common modules increase the chances of efficient reuse and recycling operation, they also feature ease of upgrade and maintenance, ease of product diagnosis, repair, and disposal, and so on.

Taking green life cycle into consideration, the authors attempted to apply the green modular concept to product design. Advantages for this study are listed as follows (Gu & Sosale, 1999; Otto & Wood, 2001; Zhang & Gershenson, 2003):

(1) Reexamination of product functions and specifications ensures that the goal of environmental protection can be achieved.
(2) Reduction in product assembly time can enhance the efficiency of production.
(3) Products or product components can be recycled, reused and disposed of more easily.
(4) The life-cycle cost estimation enables designers to bring product cost into control.

There are different perspectives with respect to measuring the product modularity. Jose and Tollenaere (2005) had made a comprehensive review regarding the modular design issue. In Section 2, the different viewpoints will be discussed. In the past, most conceptual descriptions have been rendered regarding the green-oriented modular study but a scientific methodology is rarely seen. In our study, a new methodology of green-oriented modular design will be proposed in Section 3. The approach comprises the following three parts:

(1) Clarifying the liaison intensity of components: in addition to clarifying the liaison relationships of components through visualized diagrams, the liaison intensity of components is decided by their engineering attributes.
(2) The clustering algorithm: the goal of clustering is to assign the components whose liaison intensities are stronger in the same module. In this way, the liaison intensities among different modules are relatively weaker, indicating that it is easy to connect the components if they are assigned to the same module.
(3) Green pollution and cost analysis: while changing the design specification, designers need to green pollution take and costs into consideration so that they can work out the proper design ideas in accordance with the material property to fulfill the product functions.

These three parts will be discussed in Sections 4–6 respectively. In Section 7, the design of a table lamp will be used to illustrate the methodology proposed in this study. Finally, conclusions are made in Section 8.

2. Background of product modularity

2.1. Diverse viewpoints

In the descriptive model of product functions, according to Otto and Wood (2001), modules can be defined as the integral physical structures corresponding to specific product functions. Meanwhile, the product function model is closely related to the customer's needs. Therefore, a proper modular design is able to reduce the production cost and assemble components effectively into new products to cope with the rapid change of customer's needs. The approach to meeting the customer's needs and function specifications is called the function-based modular design. In the past, different methods had been proposed to explore the function-based modular design issue; for example, Huang and Kusiak (1998) and Kreng and Lee (2004).

In the assembly-based modular design method, products are generally described by liaison graph proposed by De Fazio and Whitney (1987). Researchers need to deal with modules on the basis of network partition and analysis the subassemblies or modules from the stability viewpoint. Lee (1994) and Tseng, Chang, and Yang (2004) are typical representation for this approach of assembly-based modular design.

In general, the manufacturing-based idea does not cover the algorithm for the formation of product modules. Emphasis is often placed upon smooth connections between the design and manufacturing phases. In this domain, He and Kusiak (1996) and Kahoo and Situmdrang (2003) used manufacturing time as the criteria for efficiency evaluation.

On the other hand, the traditional low-cost and mass production model has difficulty in meeting the requirements of the contemporary era. Mass customization aims to provide customer satisfaction with increasing variety and customization without a corresponding increase in cost and lead time. Enterprises have to cope with the frequent variation of product specifications by a stock strategy of bigger numbers of components and modules in the customized environment. Therefore, the exploration of modular design will help with the production and control of mass customization. In terms of mass customization, Mikkola and Gassmann (2003) and Fujita and Yosshida (2004) offered a valuable evaluation method for this issue.

According to the green life-cycle-based concept, modular design is focused upon the environmental level. Newcomb, Bras, and Rosen (1998) used group techniques to develop modular design; Gu and Sosale (1999) used the simulated annealing algorithms to explore modular design; Qian and Zhang (2003) proposed an environmental analysis model for achieving the modular goal.

2.2. Problem formulation

As mentioned earlier, the paper attempts to focus on the green life cycle of product design. Three different problems should be taken into consideration in green modular