Available online at www.sciencedirect.com
ScienceDirect
Robotics and Computer-Integrated Manufacturing 23 (2007) 650–658
Robotics and Computer-Integrated Manufacturing
www.elsevier.com/locate/rcim

Interweaving genetic programming and genetic algorithm for structural and parametric optimization in adaptive platform product customization

L. Li[a], G.Q. Huang[a,*], Stephen T. Newman[b]

[a]Department of Industrial and Manufacturing Systems Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong
[b]Department of Mechanical Engineering, University of Bath, Bath, BA27AY, UK

Abstract

An adaptive product platform offers high customizability for generating feasible product variants for customer requirements. Customization takes place not only to product platform structure but also to its relevant parameters. Structural and parametric optimization processes are interwoven with each other to achieve the total optimality. This paper presents an evolutionary method dealing with interwoven structural and parametric optimization of adaptive platform product customization. The method combines genetic programming and genetic algorithm for handling structural and parametric optimization, respectively. Efficient genetic representation and operation schemes are carefully adapted. While designing these schemes, features specific to structural and parameter customization are considered for the simplification of platform product management. The experimental results show that the performance of the proposed algorithm outperforms that of the tandem evolutionary algorithm in which a genetic algorithm for parametric optimization is totally nested in a genetic programming for structural optimization.

Keywords: Product platform; Platform product customization; GBOM; Evolutionary algorithm; Genetic programming; Genetic algorithm

1. Introduction

Market competition forces enterprises to produce customized products with the cost and delivery time of mass production. Under the competitive environment, mass customization (MC) has embarked a new paradigm for manufacturing enterprises [1]. These enterprises on the one hand want to improve the commonality of the products to benefit from mass production. On the other hand, they intend to improve the variety of the products in the market to satisfy diverse customer requirements. To reach this goal of MC, an approach widely advocated by researchers and industrialists is to derive distinctively different products from a platform [2,3]. This approach is defined as platform product customization (PPC). A product platform is considered as a set of sub-systems and interfaces developed to form a common structure from which a stream of derivative products can be efficiently developed and produced [1]. This definition is adopted in the authors research.

There are different types of product platforms based on different MC strategies: commonality, modularity and scalability, resulting in different PPC modes as summarized in Table 1. PPC is formulated as an optimization problem. As a result, effective and useful computational approaches can be applied in this research. In PPC optimization problems, a product platform is often assumed to be given as resources and customer requirements as inputs. The solution is a variant or a set of several variants that satisfy customer requirements and constraints while optimizing performance and/or economic objectives.

A growing amount of literature exists on the three different PPC approaches recognized as scalable, configurable and adaptable.

Scalable PPC optimization is a type of parametric design optimization problem under a given product platform structure. The task of scalable PPC is to "stretch" or

*Corresponding author. Tel.: +852 2895 2591; fax: +852 2858 6535.
E-mail address: gqhuang@hku.hk (G.Q. Huang).

0736-5845/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rcim.2007.02.014

Table 1
Different modes of platform product customization (PPC)

	Scalable PPC	Configurable PPC	Adaptive PPC
MC strategy	Commonality, scalability	Commonality, modularity	Commonality, modularity, scalability
Platform type	Scalable platform	Modular platform	Adaptive platform
PPC task	Optimal parameter	Optimal structure	Optimal structure and parameter
Optimization	Parametric optimization	Combinatorial optimization	Structural and parametric optimization

"shrink" the common parameters of the platform to satisfy the given customer requirements [4]. The variants derived from the scalable platform can only have the same structural compositions. The difference between the product variants in a family is just the value of the particular components.

Configurable PPC deals with combinatorial optimization from a set of given modules and/or module options without changing their parameters [5]. Using this mode of PPC, the variant is configured from off-the-shelf modules, resulting in short lead-time. One drawback of this mode is that using the pre-designed modules, the end customized variant may not exactly match the customer requirements. It may be either over designed by selecting high-end modules or losing performance by using low-end modules.

Adaptive PPC is a combination of scalable PPC and configurable PPC. Based on the adaptive platform, this PPC approach intends to provide high customizability and reflect customer requirements more exactly [6]. In this mode of PPC, not only some of the modules can be swapped but also some modules can be scaled to configure the variant for customer requirements. Adaptive PPC, as an optimization problem, is the most difficult one compared with the other two. It includes two sub-problems: module combinatorial optimization and module parametric optimization. Since different combinations of modules may result in different structures of the end product variants. The module combinatorial optimization is considered as the structural optimization.

Evolutionary algorithms (EAs) have been applied in all three PPC methods listed in Table 1. For example, D'Souza and Simpson proposed a genetic algorithm (GA) based framework for scalable product platform design and product family customization simultaneously [7]. Chidambaram and Agogino discussed catalog-based design optimization for customization using GA [8]. As for adaptive PPC optimization, EAs appear suitable for solving such complex problems including several sub-problems interrelated with each other [9,10]. Fujita and Yoshioka proposed an optimization method, in which a successive quadratic programming is nested in brand-and-bound, which is nested in GA for commonality optimization, similarity controlling and parametric optimization in product variety design [6]. Xue employed GA and simulated annealing in a tandem structure to solve the concurrent design optimization problem considering relevant life-cycle aspects [10]. Zhang and Xue demonstrated another similar optimization method which hybridizes genetic programming (GP) and particle swarm optimization to identify the optimal product realization process alternative and its parameter values during concurrent design [11]. Li and Huang proposed a tandem evolutionary algorithm (TEA) to solve the structural optimization and parametric optimization in adaptive PPC [12]. In TEA, through nesting GA in GP, the converged optimal solution obtained by GP for structural optimization is expected to be the optimal solution of not only the structural optimization but also the adaptive PPC optimization problem.

The effectiveness of solutions gained from TEA is more or less acceptable. However, its efficiency is of some concern. Especially, the EA hybridizing other optimization techniques in a tandem structure is not viable for adaptive PPC optimization in such a case when some optional modules in the adaptive platform have no parameters to be specified. In this paper, a method named interwoven evolutionary algorithm (IEA) which interweaves GP and GA together is proposed to help designers to find the optimal product variant more effectively and efficiently. In this method, genetic operators, adopted from GP and GA, are combined together in an evolutionary process, still in a tandem structure. One difference from TEA is that the GA for parametric optimization in IEA is not executed until the optimal solution for the corresponding structure individual is obtained, but only executed for some generations. Another difference is that the parameter populations are encapsulated in modules and participate in the GP crossover and mutation operations.

The remainder of this paper is organized as follows. First, the adaptive PPC optimization problem is formulated and generally analysed in the next section. Second, the optimization method interweaving GP and GA is introduced in Section 3, together with the details of the algorithm. Experimental results are reported in Section 4 and the paper is concluded in Section 5.

2. Formulation of optimal adaptive platform product customization problem

As stated in [12], the problem of adaptive PPC is to determine the right structural composition for the desired product variant, as well as to determine the values of design parameters of the variant that satisfy customer requirements and constraints while optimizing performance and/or economic parameters concerned by the manufacturers and customers. To formulate this type of customization