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Multi-stage interactive genetic algorithm for collaborative product customization

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ABSTRACT

Products are becoming increasingly more complex and intelligent, which requires users to participate in the design process in order to meet customer demands and enhance market competition. Interactive genetic algorithm (IGA) can effectively solve the optimization problem. However, the challenge still remains for IGA to ameliorate user fatigue and reduce the noise in the process of evolution. To address the issue, a multi-stage interactive genetic algorithm (MS-IGA) is proposed, which divides the large population of the traditional interactive genetic algorithm (TIGA) into several stages according to different functional requirements. The proposed MS-IGA is then applied to the car console conceptual design system, to better capture the knowledge of users' personalized requirements and accomplish the product design. This is especially important in the field of complex product configuration design, such as in cars, personal computers, smart phones and the like. Through the users' graphic interface, customers separately evaluate product design at every different stage of its evolution, which makes the proposed algorithm more directional than the TIGA. We also introduce genetic sense units, which represent different functional modules, in order to realize the customers' collaborative design. The extensive experimental results are provided to demonstrate that our proposed algorithm is correct and efficient according to the efficiency test, convergence analysis and fatigue test for application of the product design system, including car interior and other modular product.
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1. Introduction

With the rapid deployment of mass customization [1], new products [2,3] and decision-making [4], collaborative design [5] can effectively support product innovation through the combination of collaborative work and advanced manufacturing technology, which is an important direction to pursue in current industry design technology. It is becoming crucial for enterprises to swiftly and precisely obtain user preferences and demands regarding new products, which is the key link in new product development and design, in order to save time costs and realize strategic opportunity.

More and more enterprises are emphasizing new products investigation, and introducing collaborative design systems. These collaborative product design systems increasingly influence the product design processes for many manufacturing enterprises. Therefore, the interactive genetic algorithm (IGA) can be very useful to assist in collaborative design. For example, a multi-objective rescheduling model [6] was presented by Yu et al. to realize a more rapid response to collaborative product design enterprises.

The concept of IGA [7] has been used effectively to solve the indexing optimization of the implicit performance which cannot be directly calculated by a function, but by some uncertain factors, such as customers' preferences. In this method, human cognition is integrated into the genetic algorithm by replacing the objective function of optimization, where human evaluation functions as the evolutionary individual's fitness, and participates in the evolutionary process. In the mid-1990 s, the theory and methodology of IGA [8,9] were systematically brought forward by Takagi and Aoki. Now IGA has been widely applied, which can be seen in areas such as the programming problem [10,11], color planning [12], expert knowledge [13], product design [14,15], and so forth.

There are, however, several issues and obstacles about the use of IGA. A significant example is users' fatigue, which is caused by a lot of repetitive work, tedious operation and visual weariness. There have been several approaches to ameliorate this users' fatigue [16,17], such as reducing evolutionary algebra, decreasing evaluation time, accelerating convergence algorithms, and so on. Despite the approaches could reduce users' fatigue to some extent with modification of the design space representation [18], or automatically detecting and emphasizing creative designs [19], they cannot be effectively used in the field of product design because of neglecting the different customers' preferences. Besides, there exist some other deficiencies and

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new problems to be further resolved, which are listed in the following:

(1) In the evolutionary process, the users' cognition about the evolutionary individuals would change as the population evolves. Their cognition generally develops from the much fuzzier stage to a clearer one, so they have fuzzy evaluation about the evolutionary individuals, which leads to the difference between the evaluation value and the individual's real fitness. Thus, a key question is how to speed up users' cognition or skip their cognition to improve IGA performance.
(2) When IGA is applied to product configuration, such as for a car, a mobile phone and so on, it is easy to generate irrational individuals because of dissatisfaction with constraints.
(3) In the industrial product design field, while users could participate through a graphic interface, they only passively evaluate the product based on their preferences, rather than actively participate in product research, development and design as mentioned above, which appears in fashion design systems [20,21], color planning systems of the motor car model [22], and so forth. It is necessary to resolve the problem about how to establish a customer-oriented product design system. In that case, the customer can actively participate in product research, development and design, and generate products satisfying their personal requirements.

We propose a multi-stage interactive genetic algorithm (MS-IGA) to be used collaboratively in the product design system. Specifically, the population is divided into several stages in which the population genotype gradually changes from the single to the complex. Thus, the users' population cognition burden is lessened; the evaluation process becomes relatively easy for customers, and time complexity is also reduced in the whole evaluation process. To augment this algorithm, we introduce a car interior design system application based on the new IGA. By means of a user study, we evaluate our system by comparing the algorithm with two previous IGA, and ultimately appraise the success of our approach by using a multi-stage population evolution methodology.

To summarize, this paper has three major contributions. First, the proposed algorithm provides an alternative strategy to reduce user fatigue by attempting to divide the evolutionary process. Its effectiveness is also verified. Second, a car interior design system is introduced, which gives customers the opportunity to participate in the product design process and personalize the car to suit their personal preferences. This system has proved to be an effective solution that not only satisfies each car owner's preference, but also allows for mass customized design and production. Third, this paper establishes the means by which car designers and customers can participate in collaborative design which is commensurate with their inspiration, passion and creativity.

The remainder of this paper is structured as follows: Section 2 surveys and discusses allied work by drawing on previous studies regarding IGA and mass customization. Section 3 proposes the multi-stage interactive genetic algorithm (MS-IGA), where the theory, work-flow and stages of the algorithm are stated in details. Section 4 implements the MS-IGA in a collaborative product design system, and utilizes a car interior conceptual design example to verify the algorithm performance. The experimental results demonstrate that the proposed algorithm is substantially improved when compared with the other two algorithms. Finally, Section 5 elaborates on potential future research directions.

2. Literature review

Previous work related to this paper consists of two main aspects: product customization and interactive genetic algorithm.

2.1. Product customization

This study mainly focus on how to realize the product design and production, and innovate the products against the development of mass customization to quickly and exactly capture users' preferences and demands, and establish their satisfied product modeling in optimizing and designing product. Piller et al. proposed a value-creative method of a mass production model, based on an integrated view. They concluded that flexibility of manufacturing and modern information technologies greatly enhanced mass customization, by directly interacting with each customer to increase the fidelity of products. This also means that customers greatly contributed to increasing production efficiency and decreasing production costs [23]. Hong et al. put forward a method of ANDOR, and applied it to a new product manufacturing model, that is, one-of-a-kind production. This model kept the quality and efficiency of mass production, and also provided products that satisfied customers' personalized demands [24]. Buffington et al. proposed a kind of customized production method to solve the problem of the product discontinuous innovation. They developed a complex adaptive system (CAS) model and applied it to product development and innovation [25]. Tseng et al. presented that, while going against current market environment trends, product differences and customization was in fact a new product development trend in the manufacturing industry, and they proposed a method that could produce user satisfied new product on the premise of efficiently decreasing time and design costs [26].

Order-oriented product configuration takes advantage of product customization, differences and mass production efficiency. However, this order-oriented product design (or engineer to order – ETO) is not dependent on a single product, and the key challenge of ETO customization is how to meet complicated and polytrophic design demands when customers take part in product design configuration. As a result, Hamido et al. measured and observed user behavior, and enhanced engagement accordingly by a generative interactive scenario through best performance related engagement [27]. Kristianto et al. introduced a double planning framework of two stages to respond to ETO customization in order to satisfy mass customization demands [28]. In addition, the analysis of user activity is of great significance for large-scale deployment. Zeng et al. proposed implementing a framework for the analysis of user activity on an interactive website. In this framework a user activity model is represented by a Hidden Markov Model (HMM). The method for user interest computation is provided, and user group discovery is performed [29].

Product customization design will bring huge economic benefits to enterprises and become increasingly more popular with customers. In order to more quickly and efficiently obtain users' preferences and demands in customization research and innovation of a new product, a series of interactive evolutionary computation (IEC) approaches [30] have been applied in product customization. For example, Kim et al. [31] developed a design system, and used IGA in product customization for dress design. Compared with other traditional perspectives [32], IGA enhances interaction between users and design systems, and more actively encourages user-involved design. However, users find it unacceptable if the interaction itself is complex and time-consuming, and leads to fatigue. This paper has considered IGA's advantages and universality, and applied IGA to the development process of product customization production, in order to achieve better efficiency and fully account for user fatigue issues.

2.2. Interactive genetic algorithm (IGA)

As a kind of evolutionary and optimized method, IGA treats a human's subjective evaluation as individual fitness. It differs from the traditional genetic algorithm which counts individual fitness according to fitness function. IGA typically integrates human intelligence, and obtains individual fitness designated by users in light of user

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