Collaborative Product Design for Product Customization: An Industrial Case of Fashion Product

Somlak Wannarumon Kielarova* and Prapasson Pradujphongphet

iD[3]-Industrial Design. Decision and Development Research Unit, Faculty of Engineering, Naresuan University. Phitsanulok 65000. Thailand
somlakw@nu.ac.th

Abstract. This paper proposes a new platform of collaborative product design for product customization. The proposed platform of the collaborative product design process is scoped at the internal enterprise level, which incorporates customers, designers, engineers, and technologists into a single platform. The platform can generate a design solution to the design objective. The collaborative design platform was developed in terms of an interactive design on a Computer-Aided Design (CAD) software. In the platform, customers can input the design requirements, designers can monitor the shape generation and improve the resulting design, engineers can define the manufacturing conditions, and technologists can perform the optimization of design and process parameters. At the end of the collaborative design process, a design solution, is generated as a three-dimensional (3D) model, which is directly integrated to the manufacturing process in line resulting in the generation of the physical product. This platform has been implemented in a jewelry product enterprise, and the result indicates that it can reduce time in design and manufacturing process by approximately 66%.

Keywords: Collaborative Design, Interactive Genetic Algorithm, Evolutionary Design, Design Optimization, Jewelry Design, Product Customization.

1 Introduction

Nowadays, most of enterprises are moving from mass production to mass customization to survive in both local and global competition. In product design development process, a design team is generally overwhelmed with several activities such as conceptual design, detailed design, manufacturing analysis, prototype making, testing, etc. The challenges of mass customization are providing the product variety based on the varied demands of customers at lower cost and short lead-time. Most of enterprises are trying hard to reduce the lead time of each activity in the product development process to rapidly launch out new collections and customized product. Quick response to customer needs with high flexibility in product design is needed in this digital age. Product architecture, therefore, plays a key role in forming a common product structure and allowing a variety of the product line.

Mass customization is a current key strategy in the fashion industry. Mass customization aims at satisfying the individual customer's requirements with customized products, in a short lead time and at a cost comparable to product of mass production.

This paper, therefore, aims to propose a collaborative product design platform for supporting the activities in the product.customization strategy. An interactive collaborative design was developed using a Computer-Aided Design (CAD) software package. It focuses on the product design process at the internal enterprise level. CAD is a major tool that is mostly used to model, increase the productivity of designers, improve the design quality, improve communications, and to create design and manufacturing databases [1]. The proposed platform integrates customers, designers, engineers, and technologists to collaborate along the product design process. Customers can customize their designs through the product structure, while designers can monitor the shape generation and improve the resulting designs. Engineers can analyze manufacturing conditions and manufacturability. Finally, technologist can perform optimization of the design and process parameters throughout the platform.

This paper is organized into five sections. The next section provides the related publications reporting interesting results in the areas of collaborative design and interactive genetic algorithms. Section 3 describes the computer supported platform to be utilized in product design for product customization. The case study of designing a fashion product like jewelry, as well as, the experimental results are described and discussed in Section 4. Finally, this research work and its future directions are summarized in Section 5.

2 Related Works

2.1 Collaborative Product Design and Development

Collaborative engineering is an approach utilized in optimizing engineering processes. It aims to improve product quality, shorten lead-time, improve competitive costs, and obtain higher customer satisfaction]2[. The application of collaborative engineering to product design is generally called Computer Supported Collaborative Design (CSCD), which is also called Concurrent Design, Cooperative Design, or Interdisciplinary Design.

CSCD is the product design process with collaboration among stakeholders such as designers, engineers, and other related product developers for the entire product lifecycle [2]. The functions in product design and development process cover preliminary design, detailed design, prototyping, manufacturing, testing, quality control, and other activities until the end of product lifecycle.

In a collaborative design process, product structure and product model are the most important issues and related to the CAD system that enterprises use. With collaborative product development individual users and enterprises can manage, share, and view the CAD projects.

The platform-based strategy and approach to support collaborative product development and customization was first introduced by Zha and Sriram in [3]. The approach can be used to develop guidelines for a product data management system to share product knowledge, improve product quality, shorten time-to-market, and achieve customer satisfaction. In this work, we utilized the approach described above [3] to be a guideline to construct product platform for implementing collaborative product development.

2.2 Genetic Algorithm and Interactive Genetic Algorithm

Evolutionary art]4[and design systems]5[offer an effective approach to the creation of art form. The evolutionary process in the evolutionary art and design systems works as a design parameter optimizer and a form generator. Using the advantages of this process, the designers or users can explore various design alternatives.

Genetic Algorithm (GA) is one family of Evolutionary Algorithm (EA) [6]. A typical GA requires a genetic representation of the solution domain and a fitness function to evaluate that solution domain. The major elements of a GA [5] are consisted of genotype, phenotype, genetic operators, fitness function, and selection.

Genotype is a genetic representation. It is usually encoded in the form of a string of chromosomes. It is considered as the basic unit of evolution. When more suitable chromosome structures and more suitable genotype representations are designed, it is easier for genetic operators to be applied. Genotype is typically encoded either in binary or real numbers. During an evolutionary design process, before the quality of an individual will be evaluated, genotypes are mapped onto phenotypes. Phenotypes consist of sets of parameters that represent shape or form of the studied product. Phenotypes have been represented by various techniques depending on the objectives of the system. New offspring are typically reproduced by genetic operators: crossover and mutation. Crossover is an event where parts of the chromosomes of at least two selected parents are randomly recombined to create a new set of offspring. These offspring, therefore, inherit the characteristics of each parent. Mutation modifies an arbitrary part in a genetic sequence from its original state. Mutation is typically used to maintain the population diversity during the evolution process.

Fitness function characterizes a heuristic evaluation of the solution quality. It is derived from the objective functions, to measure the qualities or the properties of the phenotypes. The fitness is usually the value of the objective function in the optimization problem being solved. It is a key factor for leading the individuals' evolution. The fitness of every phenotype must be evaluated by the fitness function. In an evolutionary design, the computational time is mostly spent in the evaluation process [5], which can take from few minutes to several hours to evaluate a single solution. This process can be improved by reducing the number of evaluations during the evolutionary process. Population size is often less than ten individuals [5], which are then evaluated rapidly in each generation. Selection is a process of choosing suitable phenotypes according to their fitness. The selection scheme can determine the generating direction of the evolutionary process.

In GA a population of individuals or phenotypes is evolved toward better solutions as part of the optimization problem. [7]. The evolutionary process starts from a population of randomly generated individuals. This is an iterative process happening within the population where each iteration called a generation. In each generation, the fitness of every individual in the population is evaluated. The more fit individuals are stochastically selected from the current population and each chosen individual is modified by crossover and mutation, to form a new generation. The new generation of candidate solutions is then used in the next iteration. GA typically terminates when either a maximum number of generations has been reached, or a satisfactory fitness level has been achieved for the population. There have been several reports that applied GA and other types of EA in design applications and creations of artworks e.g. [8-20]. Some of them integrated EA with other techniques such as artificial neural network, fuzzy set, etc., depending on the problem domains. In this paper, GA is used for shape optimization or form finding problem. Shape optimization or form finding is a technique, which has been applied successfully to various design problems, for example, product design, engineering structures [21], and architecture design [22].

Interactive Genetic Algorithm (IGA) is one type of Interactive Evolutionary Computation (IEC) used for optimization problems based on subjective human evaluation [23]. Fitness function in IEC, therefore, is substituted by human evaluation. This method has become popular in product design problems because designers are able to express their emotions and preferences onto the generated designs. In IGA, the genes of each chromosome describe a possible design [24]. The genes of each chromosome are transformed into the predefined design corresponding to that chromosome. It is presented to the user through a graphical user interface. The user serves as a fitness function, and gives scores to the candidate alternatives. Afterwards, selection and genetic operators are applied and a new generation is generated. This evolutionary process is iterated until the user reaches his/her preferred design [25]. Various applications in artistic and design applications using IGA can be found in the literature [26-30].

3 Collaborative Product Design for Product Customization

This paper proposes a collaborative design support platform. The platform of the collaborative product design is scoped for the internal enterprise. The platform incorporates customers, designers, engineers, and technologists into a single platform, as shown in Fig. 1. The collaborative design platform was developed with the aid of an interactive design feature on Computer-Aided Design (CAD) software package through web-based integration and collaboration. The mobile application was developed for inputting the design requirements by customer/user. Designers can monitor the shape generation and improve the resulting designs, and re-negotiate with customer via the mobile application. Database server was built to store and manage the databases of the designs and manufacturing knowledge and the rule-based system. These are stored on the server and provide data access for authorized designers, engineers, and technologists. At the end of the collaborative design project, a design solution is generated in the form of three-dimensional (3D) models, which is directly integrated to the manufacturing process in line, until obtaining the physical product.

In the platform of collaborative product design, the designers develop the product structure and the product model for designing the product that can be customized in various design solutions associated to design parameters known as parametric design. The engineers develop the manufacturing databases, which contain the product data, the manufacturing conditions, and the manufacturability model. The technologists develop the optimization model for optimizing the design parameters and the shape of the product.

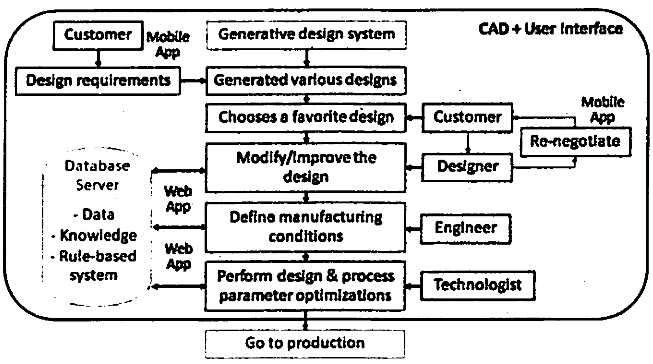

Fig. 1. The proposed collaborative product design platform.

4 An Industrial Case Study of Jewelry Halo Ring Design

The collaborative design support platform was applied for designing a mass customized product such as a fashion product. During this research project, we collaborated with a jewelry entrepreneur in Thailand. An industrial case study of halo gemstone ring design was chosen as the showcase problem. The industrial case study undertaken in the course of this project was aimed to collaborate internally among customer, designer, engineer, and technologist for automatically generating and customizing halo gemstone rings.

Halo gemstone rings are one of the most popular types of jewelry rings that enjoy a high demand in the jewelry market. Halo ring is a ring in which a center gemstone is surrounded with a set of halo stones (a set of round pave diamonds or faceted color gemstones). There are various product varieties of halo gemstone rings that can be customized according to the wishes of the customers. Initially, the designer sets up the product model as shown in Fig. 2.

We have identified a bottleneck in the design process of halo rings, which is the setting of halo gemstones surrounding the center stone with suitable equal gaps. Changing of the gemstone size and/or changing the ring size requires rearrangement or resetting of the halo gemstones on the head of the ring to obtain the proper gaps between the halo gemstones to achieve the desired aesthetics. This necessitates further metalsmith's work. The rearrangement of halo gemstones to optimize the gaps between them by manual approach with trial-and-error method is therefore relatively time-consuming. In this study, the center gemstone cuts are limited to round cut and cushion cut, while only round cut is used for the halo gemstone. The center gemstone cut dominates the setting pattern of the halo setting and is complemented by the number of halo gems, and gap size between the halo gemstones.

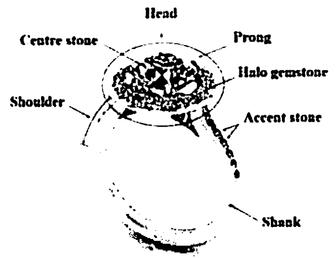

Fig. 2. Illustration of an example of product model.

In this research, IGA is used for optimizing the gaps between the halo gemstones, which employs the mathematical model of the relationships between halo gemstone setting for round-cut center gemstone by surrounding it with one layer from Kielarova et al. [31].

The prototype system was developed using Grasshopper® in Rhinoceros® 5.0 on a computer workstation with Intel Xeon CPU Processor 1.8 GHz Dual and 4.0 GB of RAM, working in 64 bit mode. The framework of the collaborative design support platform is shown in Fig. 3. The collaborative design platform was developed on Computer-Aided Design (CAD) software, named Rhinoceros® [32], with Grasshopper® plug-in [33]. Galapagos® [34], a plug-in in Grasshopper®, was employed to optimize design parameters in IGA integrated with the collaborative design support platform.

The collaborative design process starts with the customer requirements. Customer inputs his/her requirements of two design parameters: size of center gemstone and size of the halo gemstones to the system via the mobile application (see Fig. 4). The collaborative design support system then automatically works with the product model and generates the resulting 3D model. The designer, engineer, and technologist monitor the resulting 3D model, and if nothing goes wrong, the model will be passed to the production process. Otherwise, the designer can interact with the CAD platform to improve the 3D model and re-negotiate with the customer via the mobile application, the engineer can reject the model or give feedback for the model or enhance the manufacturability of the model, while the technologist can adjust the optimization model through the platform.

Comparing the proposed collaborative design support platform to the traditional approach, the proposed system is able to reduce the design and production time for this task from 45 minutes to 15 minutes. This represents a reduction of about 66%. Moreover, the platform can support mass customization of the halo gemstone rings and can be easily extended to other product models.

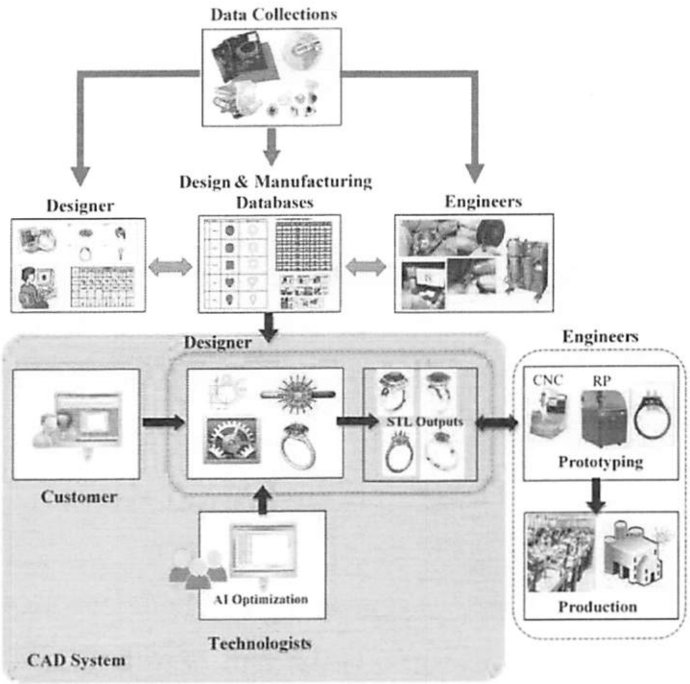

Fig. 3. The framework of the collaborative design support.

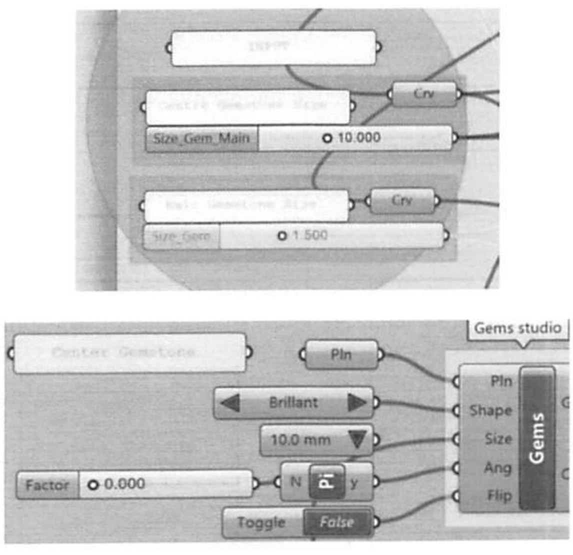

Fig. 4. Examples of customer user interfaces.

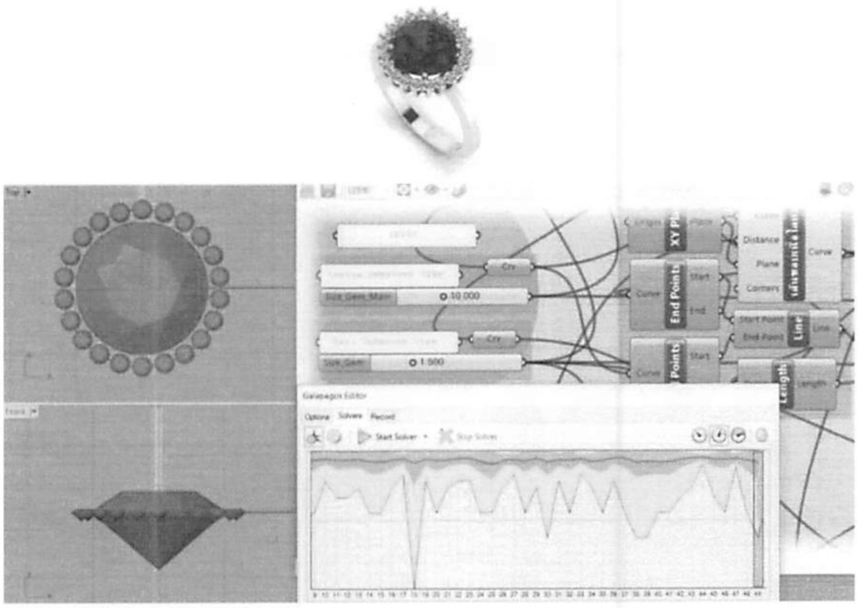

Fig. 5. An experimental result of the proposed collaborative design support platform.

5 Conclusions and Future Direction

A collaborative product design support platform was proposed for product customization applications. An industrial case study focused on designing halo gemstones rings to achieve an aesthetic appearance through the manufacturability was performed in collaboration with a jewelry entrepreneur in Thailand.

Based on the experimental results, the proposed platform is capable of automatically design the halo gemstones rings, which contain the center stone and halo gemstones, by using a set of inputs from customer. The inputs that the system requires are the size and cut of the center gemstone and the size of the halo gemstone. Those parameters are considered as a fitness function in the IGA-based collaborative design system. The system was developed by using data and information about jewelry ring design from jewelry designers and a jewelry manufacturer. The system testing conducted with the manufacturer showed that the proposed system can aid the CAD designers and reduce halo setting and arrangement time by about 66 % in comparison with the standard manual method. In future, we plan to include other product models and product structures in our system.

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