Multi-objective Aesthetic Design Optimization for Minimizing the Effect of Variation in Customer Kansei

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Abstract. Due to maturation of science and technology, companies are required to differentiate their products in terms of subjective qualities such as aesthetics whose evaluation depends on customer kansei instead of objective qualities such as performance, function and cost. In the field of kansei engineering, various methods that design products aesthetics fitted to customer kansei have been researched, but diversity of customers' kansei is becoming a big issue in those researches. Industrial products are in general designed and sold for a huge number of customers, not a single customer. Due to diversity of their kansei, that they may receive completely different impressions or have different preferences from the same product. As a result, it becomes quite difficult to design products that satisfy all customers. To overcome such difficulty, this paper proposes a new method for designing product aesthetics that give the same / similar impressions to all customers even if their kansei is diverse. To achieve this, the proposed method is based on the concept of robust design. In particular, customers evaluate existing products in questionnaire investigation. Response surfaces that approximately represent the relationships between customer's impressions received from existing products and their aesthetic elements are then calculated for each customer. Sum of squares of the difference between target impression scores and estimated ones of a design candidate is calculated for each customer as a utility. Optimal design parameters that minimize both mean and variance of all customers' utility are finally explored by using multi-objective genetic algorithm. In the case study, the proposed method was applied to artificially generated questionnaire results in which the variation in customer kansei is quantitatively controlled. The results revealed that the proposed method can design products that keep low the effect of the variation in customer kansei while achieving a design goal.

Keywords: Kansei engineering, Aesthetic design, Robust design, Response surface, Multi-objective genetic algorithm
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1 INTRODUCTION

Due to maturation of science and technology, it becomes increasingly difficult to differentiate products in terms of performance, functional feature or price. Therefore, companies are required to differentiate their products in terms of subjective and abstract qualities such as aesthetic and comfort that are evaluated by customer's feeling, which is called "Kansei" in Japanese. The quality evaluated by customer kansei is called "Kansei quality" [30].

Kansei engineering (referred to as affective or emotional engineering) [14],[15] is the field of engineering that aims to study a mechanism of humans' feeling & kansei and develop methods of measuring & analyzing humans' kansei and designing products which customers feel desirable and want. For years, in the field of kansei engineering, various methods for measuring and analyzing human's kansei and designing products based on them have been developed. As for measurement of customer kansei, most methods are based on kansei evaluation of products using questionnaire. Semantic differential method (SD method) [20] is the most widely used to quantitatively evaluate products in questionnaire investigations. In the SD method, customers quantitatively score impressions which they receive from evaluation objects using adjective pairs of opposite meanings named "Kansei words" and their evaluation scales. In addition to questionnaire investigations in which customers consciously evaluate products, measurement of bio-information such as electroencephalogram, brain activity and eye positions / movement are also used for measuring customer kansei [16]. As for analysis of measured customer kansei, various types of methods, for example, statistical techniques such as multivariate analysis and Hayashi's quantification methods, rough set theory, fuzzy set theory and artificial neural network according to a purpose. Rough set theory [22] is the method that extracts decision rules that explains the relationships between decision and condition attributes from the information of the objects having multiple attributes. In kansei engineering, customer's preference of an existing product and its aesthetic elements are considered as decision and condition attributes respectively and rough set theory extracts decision rules that explain the relationships between customer's preference and aesthetic elements from the results of questionnaire using SD method. Artificial neural network is used mainly for analyzing the relationships between customers' impressions of products measured by SD method and parameters of aesthetic features. Once learning of a neural network is finished, customer's impressions taken from new products can be inferred by inputting parameters of their aesthetic elements. In addition to the traditional methods that uses the relationships between design parameters that represents product aesthetics and customers' impressions or preferences, several methods based on deep learning [2] that has developed very rapidly in the past few years have been proposed [21]. Deep learning is a type of machine learning algorithms that uses a cascade of multiple layers and widely applied to various types of recognition tasks from still and movie images. Deep learning based methods analyze the relationships between product images themselves and customers' impressions or preferences instead of design parameters. In the traditional method, since designers design parameters that they regard important from product aesthetics and identify their values of evaluation targets, the effect of their knowledge and experience is inevitable. However, deep learning methods directly analyze product images themselves, they can overcome such problem. As for product design based on measured and analyzed customer kansei, various types of methods have been proposed. These methods generate a new aesthetic design which a customer prefers best by analyzing the relationships between the results of customer's kansei evaluation of existing products and their aesthetic elements using the methods described above. Tanaka et al. proposed the design support methods using interactive genetic algorithm [25]. Yanagisawa et al. proposed the design support methods using interactive reduct evolutionary computation [28]. Yamada et al. proposed the method to design an eyeglass frame using rough set theory [26]. Rough set theory was also used in various methods [11],[17],[19]. Hsiao et al. proposed the design support method using fuzzy theory and multidimensional scaling (MDS) method [4] and artificial neural network (NN) [5]. We proposed the design support method using self-organizing map (SOM), NN and genetic algorithm (GA) [8]. We also propose the method for selecting kansei words used for kansei evaluation [9]. In addition to product shape, the methods to design clothing pattern, texture of product surface, sound etc. have also been developed. Kamahara et al. proposed the method to design color and pattern of polka dots for clothing based on artificial neural network [7]. Akiyama et al. proposed the method to design wood grain patterns by using correlation analysis [1]. Since wood grain patterns give customers give impressions such as "peacefulness" and "composure", designed patterns are printed to product surfaces. Yanagisawa et al. proposed the method to design machine sound by using cluster analysis and correction analysis [29] Ito et al. proposed the method to design mascot characters by using rough set theory [6].

Industrial products are in general designed and sold for a huge number of customers, i.e., mass market, not a single customer. Customers that belong a mass market have a wide variety of needs, preferences, kansei, etc., so that they may receive completely different impressions or have different preferences from the same product. For example, one customer may receive "This product is stylish", another may receive "This product is not stylish". When using existing methods that don't consider variation in customers' kansei, products need to be designed for "an average customer" derived by simply averaging data collected from multiple and diverse customers. However, the data of "an averaged customer" is just the averaged data of all customers and different from every customers' data. Thus, there is highly possibility that all customers are not entirely satisfied with the products designed for "an averaged customer" and thus customer satisfaction for such products tends to be declining. To compensate the harmful effect of variation in customers' kansei, two types of design methods that consider such variation have been developed. First type is the methods that subdivide customers into smaller groups based on the similarity in their kansei and then separately design products for each group [12],[18],[27]. In particular, customers quantitatively score impressions received from existing products by using a SD method, etc. The distance among their evaluation results is calculated. The distance shows the similarity of their kansei. Customers are then subdivided into smaller groups so that ones with closer distance are collected into the same group by using a hierarchical clustering analysis, etc. We also proposed this type of method [10]. Using this type of methods, since customers belonging to the same group have similar kansei, there is a high possibility that they receive the same / similar impressions from the same product and are equally satisfied with it. On the other hand, although actual industrial products need to be designed and sold for a huge number of customers having a wide variety of kansei, the number of groups i.e. the number of product variations is limited. Thus, the number of customers per a group becomes quite large and consequently it is difficult to keep low the variation of customer kansei in each group. In addition, even if customers are grouped based on the similarity in their kansei, diversity of customer kansei still exists in each group. Hence, products still need to be designed while considering diversity of customer kansei in some way. Second type is the methods that design products that reduce the effect of variation in customer kansei on variation in customers' impressions received from them. For example, if customers receive the same / similar impressions from the product containing design option A and various different impressions from the product containing design option B, selection of design option A can reduce the effect of variation in customer kansei. To achieve such concept, the design methods based on Taguchi method [24] have been proposed [13],[23].

In this research, we focus on the variation in customer kansei as well as the methods described above and propose a new method for exploring product aesthetics that give the same / similar impressions which designers have intended to all customers even if their kansei is diverse. In other words, the proposed method explores product aesthetics that can both minimize variation in customers' impressions received from them and give specific impressions which designers have intended. In the proposed method, customers carry out questionnaire investigations where they evaluate existing products using SD method. Response surfaces that approximately represent the relationships between customer's impression scores received from existing products and design parameters of their aesthetic elements are calculated for each customer. Sum of squares of the difference between target impression scores and estimated ones received from design candidates is defined as a utility. Utility is calculated for each customer. Using multi-objective genetic algorithm, optimal design parameters that minimize both mean and variance of all customers' utility are explored. Using the proposed method, the design that is hardly affected by diversity of customer kansei while gives specific impressions to all customers can be obtained. In the case study, the proposed method was applied to artificially generated questionnaire results in which the variation in customer kansei is quantitatively controlled. The results revealed that the proposed method can design products that keep low the effect of the variation in customer kansei while achieving a design goal.

The rest of this paper is organized as follows. The details of the proposed method is explained in section 2. To confirm the effectiveness of the proposed method, it is applied to a car exterior design, as described in section 3. Finally, the results of this paper is summarized in section 4.

2 PROPOSED METHOD

In general, customers have their own kansei, they may receive completely different impressions or have different preferences from the same product. Therefore, it is quite difficult to design a product that gives the similar / same impressions to all targeted customers. However, variation in customer kansei is not always uniform; in other words, customers have the similar / same kansei in some part and have completely different kansei in other part. As a result, it is possible that the variation in customers' impressions received from design A is small while the one received from design B is large. Therefore, the basic concept of the proposed method is to evaluate robustness of designs against variation in customer kansei and explore the design that achieves a design goal and has high robustness. In that sense, the proposed method is a type of robust design / optimization methods developed for years. The proposed method consists of the following 3 steps:

Step 1: Questionnaire investigation
Step 2: Calculation of response surfaces
Step 3: Exploration of product aesthetics

In the first step, impressions received from existing products are quantitatively measured for each customer by questionnaire investigation. In the second step, based on the questionnaire results, response surfaces that approximately represent the relationships between customer's impressions received from existing products and design parameters of their aesthetics are calculated for each customer. In the third step, objective functions that represents the robustness and achievement level against a design goal of designs are defined by using response surfaces for all customers and an optimal design is explored by using multi-objective genetic algorithm.

The following sections explain their details.

2.1 Preparation of the Proposed Method

In the proposed method, questionnaire investigation using SD method is carried out to quantitatively measure impressions received from products. In the preparation step, questionnaire sheets are prepared by following the following procedures. A designer selects the same types of existing products as the design target and collects their photos. Photos taken under the similar / same conditions are desirable. A designer selects adjective pairs of opposite meanings named "Kansei words" suited for representing impressions taken from the design target and existing products to be evaluated. A designer then makes questionnaire sheets using photos, pairs of kansei words and their 5-point or 7-point evaluation scales.

In the proposed method, response surfaces that approximately represent the relationships between customer's impressions received from existing products and design parameters of their aesthetic elements are calculated. In the preparation step, a designer selects design parameters that represent product aesthetics. Since the number of design parameters should be limited in order to generate accurate response surfaces, a designer select only important design parameters. A designer then identifies their values for each existing product.

2.2 Step 1: Questionnaire Investigation

Using questionnaire sheets, customers individually carry out kansei evaluation of existing products. They score their impressions received from existing products by using the pairs of kansei words and their 5-point or 7-point evaluation scales printed in questionnaire sheets.

2.3 Step 2: Calculation of Response Surfaces

Using the questionnaire results, response surfaces that approximately represent the relationships between customer's impressions received from existing products and their aesthetics are calculated for each pair of kansei words and for each customer. In particular, evaluation scores of a pair of kansei words are handled as response variables while design parameters of product aesthetics are handled as independent variables. The response surface of pair of kansei words j of customer i is denoted as $F_{ij}(\boldsymbol{x})$. Where, $\boldsymbol{x} = \{x_1, x_2, \cdots x_m\}$ is m design parameters.

In an aesthetic design, some design parameters are in the form of continuous values and others are in the form of options. Therefore, some design objects contain only continuous design parameters, others contain only options and still others have both types of design parameters. Various types of response surfaces have been proposed. It is desirable to select the method best suited for the type of the design target. For example, in the case of the case study, every design parameter is continuous one, so that the relationship is approximated by using polynomial function.

2.4 Step 3: Exploration of Product Aesthetics

The goal of design methods in the field of kansei engineering including the proposed method is to obtain the product aesthetics that gives impressions which a designer intends to customers. Thus, objective function of such methods is basically based on the difference between target impression scores and estimated ones of a design candidate. In the proposed method, such objective function is defined in the below equation and named "Utility".

$$G_i(\boldsymbol{x}) = \sum_{j=1}^{n} \left(y_j - F_{ij}(\boldsymbol{x})\right)^2 \tag{1}$$

Where, $G_i(\boldsymbol{x})$ is the utility function of customer i, $\boldsymbol{x} = \{x_1, x_2, \cdots x_m\}$ is m design parameters $F_{ij}(\boldsymbol{x})$, is the response surface of pair of kansei words j of customer i as described in the previous section, $\boldsymbol{y} = \{y_1, y_2, \cdots y_n\}$ is target impression scores which a designer intended of n pairs of kansei words. If the number of customer is 1 that is not the target of the proposed method, the optimal product aesthetics can be obtained by simply minimizing a utility. As described before, the purpose of the proposed method is to explore the product aesthetics that can both give specific impressions which designers have intended and minimize variation in customers' impressions received from them. Therefore, to evaluate the former purpose, the following equation is defined as the first objective function F_1 of the proposed method.

$$F_1(\boldsymbol{x}) = \frac{1}{n}\sum_{i=1}^{n} G_i(\boldsymbol{x}) \tag{2}$$

Where, n is the number of customers. On the other hand, to evaluate the latter purpose, the following equation is defined as the second objective function F_2.

$$F_2(\boldsymbol{x}) = \frac{1}{n}\sum_{i=1}^{n} (G_i(\boldsymbol{x}) - \bar{G})^2 \tag{3}$$

Where, n is the number of customer and $\bar{G}$ is the average of the utility of all customers. Since these two objective functions conflict each other, i.e. have a trade-off relationship, this design problem is a type of multi-objective optimization problems. To obtain its optimal results, multi-objective genetic algorithm is used in the proposed method. Multi-objective genetic algorithm is a type of genetic algorithm. It can obtain a set of Pareto optimal solutions, i.e. Pareto front by evaluating more than one objective function. Since multi-objective genetic algorithm [3] is a metaheuristic, it can efficiently obtain Pareto front. After obtaining a Pareto front, a designer select one design solution by considering the balance between two objective functions.

3 CASE STUDY

To evaluate how the proposed method reduces the impact of variation in customer kansei, a numerical case study is carried out. In the case study, to compare two cases in which variation in customer kansei is small and large, questionnaire results i.e. customers' impression scores are artificially and numerically generated instead of carrying out actual questionnaire investigations.

3.1 Details of the Case Study

In the case study, a design target consisting of 4 design variables were assumed. All of design variables take continuous values and their range is 0 to 1. By changing them, 1296 virtual products were generated. Three pairs of kansei words and their 5-point evaluation scales were prepared for evaluating these products. Since this case study was just a numerical example, neither a concrete product, design variables nor pairs of kansei words were not assumed. As for customers who make kansei evaluation, 100 virtual customers were assumed and their questionnaire results regarding generated virtual products were generated. As repeatedly mentioned in this paper, customer kansei is divers. However, their variation is not completely random, in other words, their questionnaire results have a certain degree of trend or similarity. This is because most industrial products are designed and sold for the customer group having certain attributes. Therefore, their questionnaire results were generated by the following procedure. First, we generated the questionnaire results of "reference customer" that show the trend or average results among virtual customers. In particular, we arbitrarily defined the functions that approximately represent the relationships between evaluation scores and design variables and generated reference questionnaire results by inputting design variables to them. We then generated the questionnaire results of 100 virtual customers by adding random values to the reference questionnaire results. Added random values represents the variation in customer kansei. By configuring appearance probability of each random values, degree of variation in customer kansei can be freely controlled. Their detailed probability is described in the next paragraph. As for response surfaces, cubic polynomial interpolation was used.

To discuss the influence of variation in customer kansei, two cases were carried out. In Case1, multi-objective optimization considering the diversity of customer kansei was carried out by using the proposed method. Optimization was carried out by using two set of questionnaire results; small and large variation in customer kansei. Specific impact of degree of variation in customer kansei on customers' evaluation score is as bellow. In the case in which variation in customer kansei is large, customers took the same evaluation scores as the reference customer (reference score) with the probability of 30% while the reference scores -3, -2 and -1 with the probability of 5%, 11% and 19% respectively and +1, +2 and +3 with the probability of 19%, 11% and 5% respectively for the first pair of kansei words. As for the second pair of kansei words, they took the reference scores -3, -2, -1, ±0, +1, +2 and +3 with the probability of 3%, 9%, 16%, 44%, 16%, 9% and 3% respectively. As for the third pair of kansei words, they took the reference scores -2, -1, ±0, +1 and +2 with the probability of 2%, 7%, 82%, 7% and 2% respectively. In the case in which variation in customer kansei is small, they took the reference scores -2, -1, ±0, +1 and +2 with the probability of 6%, 11%, 66%, 11% and 6% respectively. As for the second pair of kansei words, they took the reference scores -2, -1, ±0, +1 and +2 with the probability of 2%, 7%, 82%, 7%, and 2% respectively. As for the third pair of kansei words, they took the reference scores -1, ±0 and +1 with the probability of 4%, 82% and 4% respectively. In Case2, for comparison, questionnaire results of all customers were averaged and single-objective optimization not considering the diversity is carried out by using averaged data. As for the function for obtaining reference scores, the functions of the first and second pair of kansei words were based on the multivariate normal distribution while the function of the third pair of kansei words was based on the linear function. Target scores of 3 paris of kansei words in every case were 2, 3 and 4 respectively.

3.2 Results

Figure 1 (a) and (b) show the cases in which variation in customer kansei is large and small respectively. The results of Case2 were much worse than the results of Case1 in both cases, they can't be represented in the figures.

The results show that the mean and variance of customers' utility are not compatible. Their optimal relationships are obtained in the form of Pareto curves. The comparison between Case1 and Case2 in both cases shows that the proposed method can keep low the impact of the variation in customer kansei. The comparison between two cases in which variation in customer kansei is large and small shows that the smaller variation in customer kansei, the smaller variation in customers' evaluation scores of the obtained products.

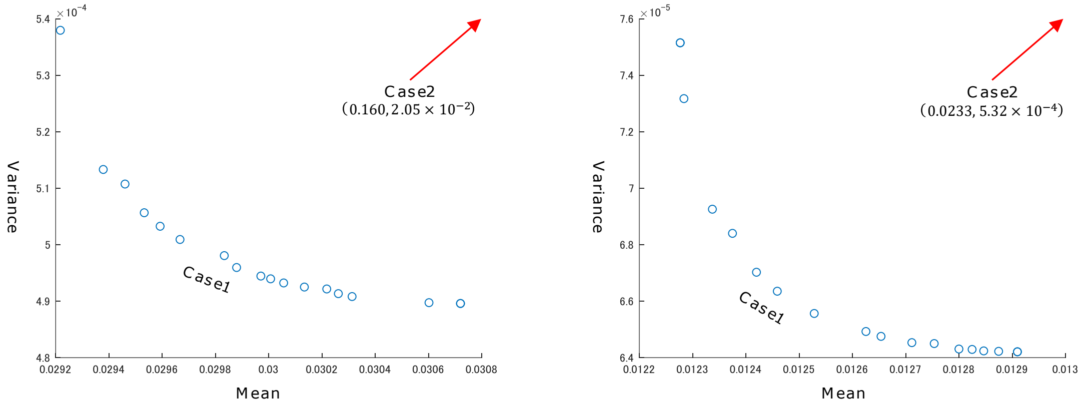

Figure 1: Optimization results: (a) Variation in customer kansei is large, (b) Variation in customer kansei is small.

4 CONCLUSION

Industrial products are in general designed for many customers. However, due to diversity of customer kansei, customers may receive different impressions or have different preferences from the same product. As a result, customer satisfaction for industrial products tends to be declining.

To overcome this problem, this paper proposed a new method for obtaining product aesthetics that give the same / similar impressions to all customers even if their kansei is diverse. In the proposed method, response surfaces that approximately represent the relationships between customer's impression scores received from existing products and their design parameters are calculated for each customer based on the questionnaire results. Square-sum of the difference between target impression scores and ones of design candidates estimated by using response surfaces is defined as a utility for each customer. Using multi-objective genetic algorithm, optimal design parameters that minimize both mean and variance of all customers' utility are explored. Using the proposed method, the design that is hardly affected by diversity of customer kansei and gives specific impressions to customers can be obtained.

In the case study, the proposed method was applied to artificially generated questionnaire results in which the variation in customer kansei is quantitatively controlled. The results revealed that the proposed method can design products that keep low the effect of the variation in customer kansei.

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