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

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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".

In the field of emotional engineering or kansei engineering, the methods for measuring customer kansei or the impression of products have been developed and applied to many case studies. In these methods, semantic differential (SD) method [9] is widely used. In addition, various aesthetic design methods based on analysis of measured customer kansei have also been developed. These methods generate a new aesthetic design which a customer prefers best by revealing the relationships between the results of customers' kansei evaluation of the same type of existing products as the design target and their aesthetic features. In these method, various analysis methods such as artificial neural network [2] [3], fuzzy set theory [1], interactive reduct evolutionary computation [14], multi-dimensional scaling [1], rough set theory [4] [5] [8] [10] [12], self-organizing map [3] etc. are used.

In general, industrial products are designed and sold for many customers, not a single customer. However, due to diversity of customer kansei, customers may receive completely different impressions from the same product or have different preferences for the same product. For example, one customer may receive "This product is stylish", another may receive "This product is not stylish". As a result, customer satisfaction for industrial products tends to be declining. To overcome such difficulty, several types of methods have been proposed. First type is the methods that group customers based on the similarity in their kansei and separately design products for each group [4] [6] [13]. We also proposed this type of method. 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 satisfied with it. On the other hand, these methods have the following problems. Actual industrial products need to be designed and sold for thousands, ten-thousand or more customers. However, since the number of groups i.e. the number of product variations is limited, 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 minimize 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 have been proposed [7] [11].

In this research, we focus on the variation in customer kansei as well as those methods and propose a new method for obtaining product aesthetics that give the same / similar impressions to all customers even if their kansei is diverse. In other words, the proposed method explores product aesthetics that minimize the effect of variation in customer kansei on variation in customers' impressions received from products while achieve design targets. In the proposed method, questionnaire investigations of existing products are carried out by customers and response surfaces that approximately represent the relationships between customer's impression scores revived from existing products and parameters of their aesthetic elements are calculated for each customer. Sum of squares of a difference between target impression scores and estimated ones received from design candidates 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.

Proposed method:

The purpose of the proposed method is to design products that give the same / similar impressions to all customers even if their kansei is diverse. This basic concept is similar to robust design / optimization. Design methods proposed in the field of kansei engineering can be classified into two types. The former focuses on customers' impressions received from products and the latter focuses on customers' preferences for products. The proposed method belongs to the former type. To achieve this, the proposed method consists of the following 3 steps:

Step1: Questionnaire investigation
Step2: Calculation of response surfaces
Step3: Exploration of product aesthetics

The following sections explain their details.

Step0: Preparation of the proposed method

A designer prepares photos of the same type of existing products as the design target and selects adjective pairs of opposite meanings named "Kansei words" suited for representing impressions taken from the design target and existing products. A designer then makes questionnaire sheets using photos, pairs of kansei words and their n-point evaluation scales.

A designer also selects aesthetic elements suited for representing aesthetics of the design target and existing products and identifies parameters / options of existing products.

Step1: Questionnaire investigation

Using questionnaire sheets, customers carry out kansei evaluation of existing products. They score their preference and impressions of existing products by using the pairs of kansei words and their evaluation scales printed in questionnaire sheets.

Step2: Calculation of response surfaces

Using the kansei evaluation results obtained in Step1 and design parameters of existing products identified in preparation step, response surfaces that approximately represent the relationships between customer's impressions received from existing products and their aesthetic elements 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.

Step3: Exploration of product aesthetics
Using response surfaces obtained for each pair of kansei words and for each customer, utility function of customer i is defined by the below equation.

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

Where, $\boldsymbol{x} = \{x_1, x_2, \cdots x_m\}$ 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 of n pairs of kansei words.

If the design candidate whose scores of all pairs of kansei words are equal to the target scores is found, its utility value becomes zero. Utility function is defined for each customer and customers have their own different response surfaces, so that different utility values are different for the same design candidate in each customer. Therefore, multi-objective genetic algorithm is carried out by using mean and variance of utility values of all customers as objective functions. Optimal result of multi-objective optimization is obtained in the form of Pareto curve. A designer selects one design from the obtained Pareto curve considering a balance between mean and variance of utility values.

Case study:
To evaluate the influence of variation in customer kansei, a numerical case study is carried out. In the case study, to control the variation in customer kansei and consistency of kansei evaluation, questionnaire results are artificially and numerically generated and used instead of carrying actual questionnaire investigations.

Details of the case study
100 virtual customers were assumed and their questionnaire results were generated by the following procedure. First, we generated reference questionnaire results. 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 questionnaire results of 100 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. A virtual design target has 4 design variables. Their range is 0 to 1. The number of pairs of kansei words is 3. Since this case study is just a numerical example, a concrete product nor pairs of kansei words are not assumed. As for response surfaces, cubic polynomial interpolation are 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. 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.

Results
Fig.1 and 2 show the results of two cases. Fig.1 (a) and (b) show the cases in which variation in customer kansei is large and small respectively. In both cases, 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 and their optimal relationships are obtained in the form of Pareto curves. A comparison between Case1 and Case2 shows that the proposed method can keep low the effect of the variation in customer kansei.

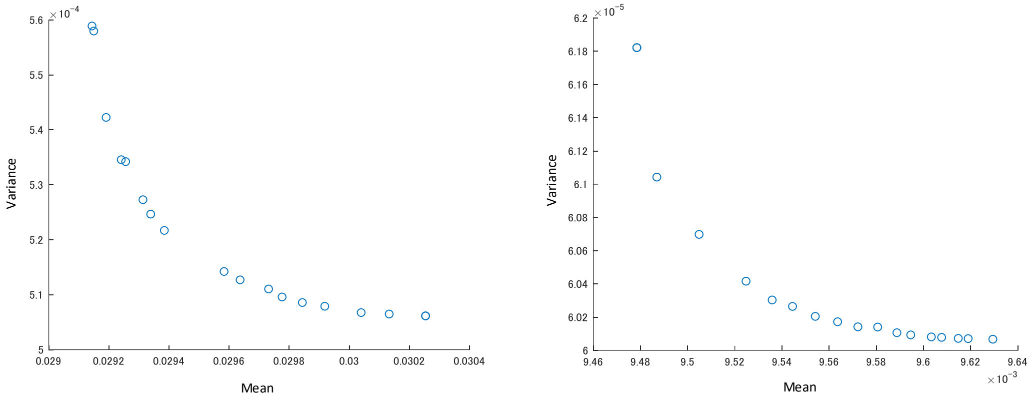

Fig.1: Optimization results: (a) Large variation in customer kansei, (b) Small variation in customer kansei.

Conclusion:

In general, industrial products are 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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