COMPUTER-AIDED DESIGN & APPLICATIONS, 2016
VOL. 13, NO. 3, 281–288
http://dx.doi.org/10.1080/16864360.2015.1114385

A Method for Supporting Aesthetic Design Based on the Analysis of the Relationships between Customer Kansei and Aesthetic Element

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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 heavily depends on customer feeling i.e. kansei. In this research, we develop a new aesthetic design support method based on analysis of customer kansei. In the proposed method, a customer makes kansei evaluations of existing products. Based on their result, a three-layer model that represents the relationships between customer's kansei and product aesthetics is constructed by using SOM (Self-organizing map) and traditional artificial neural network. After constructing the model, a customer indicates his / her needs for a new product and optimal aesthetic design is explored by using genetic algorithm. In the case study, the proposed method is applied to office chair design and its effectiveness is confirmed.

KEYWORDS
Aesthetic design; Kansei engineering; self-organizing map; artificial neural network; genetic algorithm; office chair design

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" [27].

In the field of emotional engineering or kansei engineering [16], [17], [18], the methods for measuring customer kansei or the impression of products have been developed and applied to many case studies [9], [13], [28]. In these researches, semantic differential method (SD method) [19] is widely used. SD method scores the impression which a customer receives from products using adjective pairs of opposite meanings named "Kansei words". In addition to measurement, methods for supporting aesthetic design by utilizing customer kansei have also been developed. These methods derive the 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. Tanaka et al. proposed the design support methods using interactive reduct evolutionary computation [23], Yanagisawa et al. proposed the design support methods using interactive genetic algorithm [25]. Yamada et al. proposed the method to design an eyeglass frame using rough set theory [20], [24]. Hsiao et al. proposed the design support method using fuzzy theory and multidimensional scaling (MDS) method [5] and artificial neural network [6]. In their latter research, the relationships between the shapes of existing products and kansei words which a customer receives from them are analyzed by artificial neural network. If the network is once constructed, image feelings which a customer receives from a new product can be predicted. In addition to product shape, the methods to design clothing pattern, texture of product surface, sound etc. based on kansei evaluation have 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 [26] Ito et al. proposed the method to design mascot characters by using rough set theory [8]. Some researchers focused on robustness in kansei engineering and proposed robust design methods using taguchi's method [12], [22]. Schütte et al. defined a general model

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of kansei engineering system and summarized & classified present systems [21]. In the field of CG or CAD, the concept of aesthetic curves and surfaces is proposed by Harada et al. [3], [4] and their formulation and application of aesthetic curves and surfaces have been studied [14], [29]. Gianninia et al. identified and classified styling properties and features that affect product aesthetics [2].

In this research, we develop a new aesthetic design support method based on customer's kansei evaluation. The feature of the proposed method is to construct a three-layer model that represents the relationships between customer's kansei and product aesthetics. Three-layer means two layers of kansei words which a customer receives from a product and one layer of aesthetic elements of a product. Two layers of kansei words come from mori's kansei evaluation model [15]. Mori proposed three-layer kansei evaluation model based on personal construct theory [10]. Fig. 1 shows its model. A lower layer is named "Perception". Kansei words belonging to the layer are concrete and closely connected with human perception. Examples of lower level kansei words are Angulated, Rounded and Rugged. A middle layer is named "Image". Kansei words of the layer are more abstract than ones of a lower layer and evoked by integrating lower level kansei. Examples of middle level kansei words are Fancy, Sharp and Simple. An upper layer is named "Total evaluation". Kansei words of the layer are most abstract, synthetic and integrative. Examples of upper level kansei words are Attractive, Beautiful and Like. In general, evaluation of lower level kansei is relatively common while evaluation of upper level kansei is highly individual. This model is widely recognized and used in various researches.

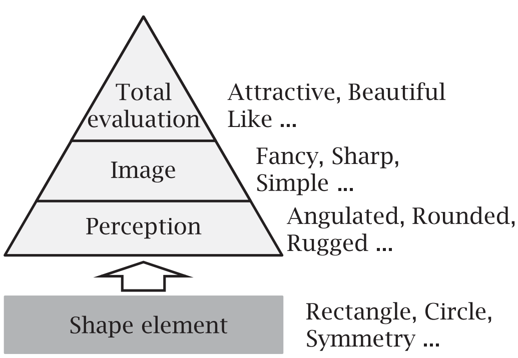

Figure 1. Hierarchy of kansei evaluation.

From the mori's kansei evaluation model, the proposed method uses upper and middle level kansei words. To construct a three-layer model of the proposed method, both aesthetics of existing products and upper level kansei words are evaluated by using a set of middle level kansei words. After two types of evaluations, a three-layer model is constructed using self-organizing map (SOM) [10] and traditional artificial neural network (ANN). SOM analyzes and visualizes the similarity of upper level kansei words based on the evaluation results of upper level kansei words by using a set of middle level kansei words. The visualized similarity is named "Kansei space". Kansei space helps a customer understand the similarity of upper level kansei words and express customer needs by only indicating a point on the space. ANN analyzes the relationships between middle level kansei words and aesthetic elements based on the evaluation results of existing products. Finally, Genetic algorithm (GA) explores the optimum parameters of aesthetic elements that best fit to the customer needs. Note that the proposed method is for a single customer, not a group of customers. Fig. 2 shows the concept of the three-layer model of the proposed method. Although the method that analyzes the relationships between kansei words and aesthetic elements by using ANN has already been proposed, the novelty of the proposed method is to construct a three-layer model that consists of upper and middle level kansei words and aesthetic elements and kansei space that visualizes the similarity among upper level kansei words. Three-layer model enables a customer to express his / her needs in the form of upper level kansei words, while kansei space helps a customer to understand his / her implicit and complicated kansei.

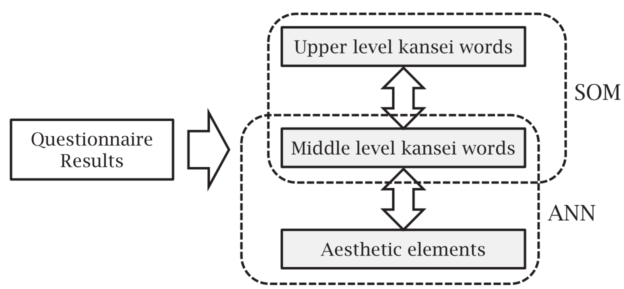

Figure 2. Three-layer model of the proposed method.

The rest of the paper is organized as follows. Section 2 describes the details of the proposed method. Section 3 describes the case study. In the case study, the proposed method is applied to office chair design. Finally, Section 4 summarizes the results of the paper.

2. Proposed Method

Fig. 3 shows the overview of the proposed method. First of all, questionnaire investigation is conducted. In this investigation, a customer evaluates existing products and upper level kansei words by using a set of middle level kansei words. Based on the questionnaire results, a kansei space that represents the relationships among upper level

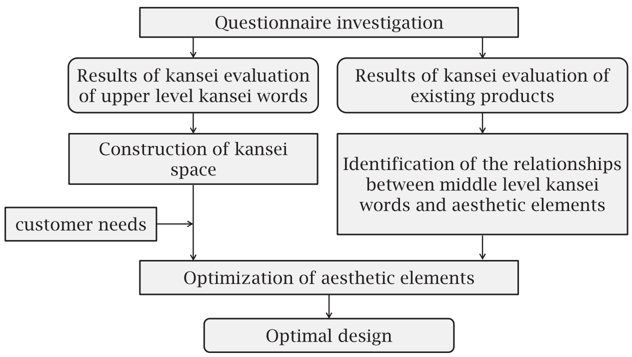

Figure 3. Flowchart of the proposed method.

kansei words and between upper and middle level kansei words is constructed by using SOM and the relationships between middle level kansei words and aesthetic elements are identified by using ANN. A customer looks at the kansei space and expresses his / her needs in the form of the point on the kansei space. Finally, genetic algorithm explores the optimal parameters of aesthetic elements that best fit to his/her needs.

The below sections explain the details of the proposed method.

2.1. Preparation of the proposed method

A user of the proposed method prepares photos of the same sort of existing products as a design object and selects upper and middle level kansei words suitable for evaluating their aesthetics. Using them, a user prepares two types of sheets for questionnaire investigation. One is the sheet in which a photo of an existing product, a set of middle level kansei words used for evaluating that product and their evaluation scale are printed. The other is the sheet in which an upper level kansei word, a set of middle level kansei words used for evaluating that upper level kansei word and their evaluation scale are printed.

A user also selects aesthetic elements that have a major impact on aesthetics of existing products and a design object, defines their parameters and measures parameters of existing products. The proposed method can handle both discrete (selective) and continuous parameters. In the case of office chair design, the number of legs (3, 4, or 5-legged) and types of armrest (T-shape, ring shape or no armrest) are the former examples while outer shapes of a back and seat (outer shape is represented by curves and coordinates of their control points are handled as parameters) are the latter examples.

2.2. Step1: questionnaire investigation

Using questionnaires, a customer evaluates existing products and upper level kansei words. In particular, a customer evaluates his / her impression of existing products represented in the questionnaires by using a set of middle level kansei words on a scale of 1 (not at all) to 7 (very much). A customer also evaluates his / her impression of upper level kansei words in the same manner.

2.3. Step2: construction of a three-layer model

Based on the questionnaire results, a three-layer model that represents the relationships between upper level kansei words, middle level kansei words and aesthetic elements is constructed using SOM and traditional ANN.

As for the relationships between upper and middle level kansei words, SOM analyzes and visualizes the similarity of upper level kansei words based on the questionnaire results (the evaluation results of upper level kansei words by using a set of middle level kansei words).

Self-organizing map (SOM) is a type of ANN that produces a low-dimensional, discretized representation of the input space of the training data, called a map. SOM is useful for visualizing the relationships among high-dimensional data in the form of low-dimensional map (typically two-dimensional). In the proposed method, a 10*10 array of nodes is considered. Each node contains a weight vector and its dimension is same as the dimension of an input vector, i.e. the number of middle level kansei words used for evaluating upper level kansei words in Step1. An evaluation result of each upper level kansei word is used as an input vector. The procedure of SOM is as follows.

1. Weight vectors of all nodes on a map are randomized in the 1 to 7 range.
2. An input vector is selected.
3. The similarity between the input vector and the weight vectors of all nodes based on the Euclidean distance are calculated and the node that produces the smallest distance is found out. This node is called the best matching unit (BMU).
4. The weight vectors of the nodes in the neighborhood of the BMU and the BMU itself is updated by the below equation.

$$\begin{aligned} \boldsymbol{W_v}(t+1) &= \boldsymbol{W_v}(t) + \Theta(t)(\boldsymbol{D} - \boldsymbol{W_v}(t)) \\ \Theta(t) &= a\sigma(t)e^{-\frac{diff}{\sigma(t)}} \\ \sigma(t) &= e^{-\frac{t}{100}} \\ diff &= \|\boldsymbol{D} - \boldsymbol{W_v}(t)\|^2 \end{aligned} \tag{2.1}$$

Where, $\boldsymbol{W_v}$ is the weight vector of node v. $\boldsymbol{D}$ is the input vector. $\Theta(t)$ is a restraint due to distance from BMU and iteration progress. t is the current iteration. In this paper, the nodes in the 1-ring and 2-ring neighborhood of the BMU are considered. a of the nodes in the 1-ring and 2-ring neighborhood are 1 and 0.3 respectively.

5. Until the number of iteration is reached to the limit, the process is repeated from 2.
6. After iterative calculation, the similarity between each input vector and the weight vectors of all nodes is calculated and the nodes having the weight vectors nearest to each input vector are found out. Upper level kansei words that correspond to each input vector are displayed on those nodes as shown in Fig. 4. The map in which upper level kansei words are displayed is named "Kansei space". The distance between upper level kansei words displayed in the map shows their similarity. In the case of Fig. 4, since "Attractive" and "Cool" are placed on the same node, a customer feels they are the same in meaning. Since "Stylish" and "Beautiful" are placed on the adjacent nodes, a customer feels they are similar in meaning (but not the same). On the other side, since "Cute" is far from the other words, a customer feels that the meaning of "Cute" is far from the meanings of the other words. The final weight vectors of all nodes are used to indicate customer needs in Step3.

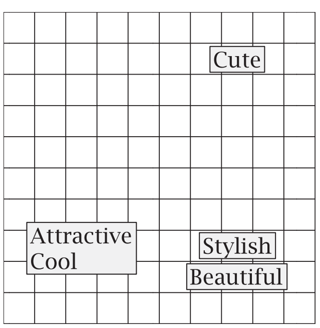

Figure 4. Example of a kansei space.

As for the relationships between middle level kansei words and aesthetic elements, they are identified from the questionnaire results (the evaluation results of existing products by using a set of middle level kansei words) by using traditional ANN. As shown in Fig. 5, a network consists of three layers. Nodes of input layer correspond to parameters of aesthetic elements while nodes of output layer correspond to a weight vector of middle level kansei words. The questionnaire results are used as training data. A network is trained by using backpropagation method. The details of training procedure using backpropagation method are shown in the reference.

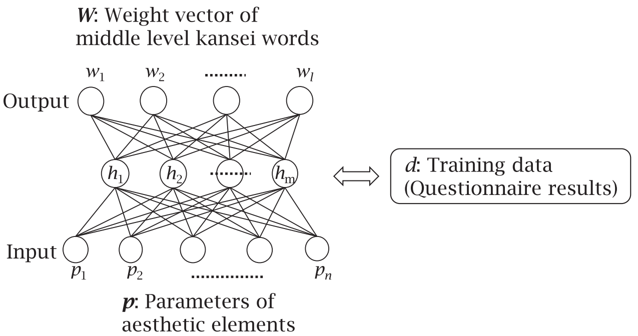

Figure 5. Construction of the neural network.

2.4. Step3: Input of customer needs

A customer takes a closer look at the kansei space obtained in Step2 to deeply understand his / her implicit and complicated kansei and expresses his / her needs by indicating a point on the kansei space as shown in Fig. 5. The distance between the point which a customer indicates and each upper level kansei word shows how a customer strongly hopes to receive those impressions from a new product. Therefore, a customer thinks what impressions he / she truly hopes and indicates a point on the kansei space. In the case of Fig. 5, a customer hopes an attractive, beautiful, cool and stylish product. Although a map of SOM is discrete and weight vectors are only defined on map's nodes, a user can indicate any point without being bound by discrete map's nodes. On the assumption that nodes' weight vectors are placed on the center of nodes' rectangles as shown in Fig. 6, the weight vector of the point which a customer indicates is calculated by interpolating weight vectors of four nodes around the point by the below equation. Fig. 7

$$\boldsymbol{W_{needs}} = (1-t)(1-s)\boldsymbol{W_{i,j}} + t(1-s)\boldsymbol{W_{i+1,j}} + (1-t)s\boldsymbol{W_{i,j+1}} + ts\boldsymbol{W_{i+1,j+1}} \quad (2.2)$$

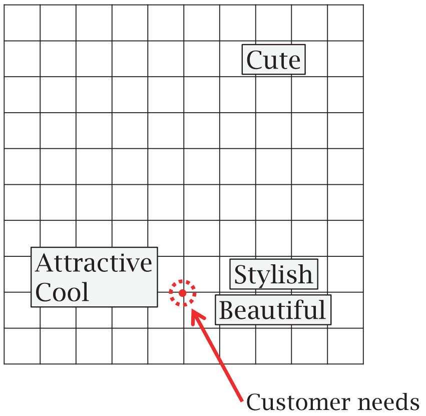

Figure 6. Input of customer needs.

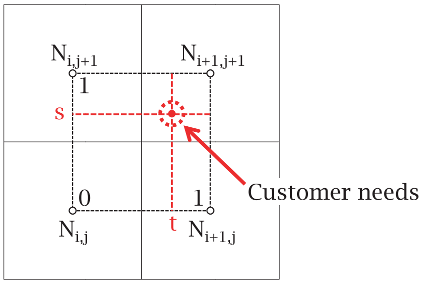

Figure 7. Calculation of the weight vector of the customer needs.

Where, $W_{i,j}$, $W_{i+1,j}$, $W_{i,j+1}$, $W_{i+1,j+1}$ are the weight vectors of the four nodes around the point which a customer indicates. t and s are the coordinates of the point which a customer indicates.

W_{needs} represents the impressions which a customer hopes to receive from a new product in the form of a weight vector of middle level kansei words. Wneeds are the design target of a new product.

2.5. Step4: optimization of aesthetic elements

In Step2 and 3, the network that represents the relationships between the values of middle level kansei words and the parameters of aesthetic elements are obtained and the customer needs for a design target are expressed in the form of the value of middle level kansei words. In Step4, based on them, parameters of aesthetic elements that best meet the customer needs represented in the form of the value of middle level kansei words are explored by using GA. Design variables of GA are parameters of aesthetic elements. Fitness function of GA is formulated as follows.

$$f(\boldsymbol{p}) = \|\boldsymbol{W}_{needs} - \boldsymbol{W}(\boldsymbol{p})\|^2 \tag{2.3}$$

Where, $\boldsymbol{p}$ are the parameters of aesthetic elements of a design proposal. $\boldsymbol{W}_{needs}$ is the target weight vector of middle level kansei words derived from the customer needs. $\boldsymbol{W}(\boldsymbol{p})$ is the weight vector of middle level kansei words estimated from $\boldsymbol{p}$ by using the constructed network.

3. Case Study

To test the effectiveness of the proposed method, the proposed method is applied to office chair design.

3.1. Details of the case study

As for aesthetic elements, outer shape and thickness of a back and a seat and type of a leg and an armrest are considered as aesthetic elements of a chair. Outer shape of a back and seat is represented by B-spline curve. To reduce the number of parameters of aesthetic elements, a back and seat are considered as flat and bilaterally symmetric. As shown in Fig. 8, a back consists of curves A, B and C, while a seat consists of curves D, E and F. Curve A, B and C are defined by 5 control points while Curve D, E and F are defined by 4 control points. a1′, a2′, c1′, c2′, e1′, e2′, f1′ and f2′ are symmetrical to a1, a2, c1, c2, e1, e2, f1 and f2 respectively. a3 and c3 are placed on a line of symmetry. Coordinates of control points are used as parameters of aesthetic elements. To ensure that a B-spline curve passes through start and end control points, knots are added at start and end of knot vector. As for a leg, 4-legged or 5-legged shown in Fig. 9 can be selected. As for an armrest, a chair with armrests or without armrests shown in Fig. 10 can be selected. To wrap up, 28 parameters of coordinates of control points, 2 parameters of thickness of a back and a seat, 2 selective parameters of types of a leg and armrest are defined.

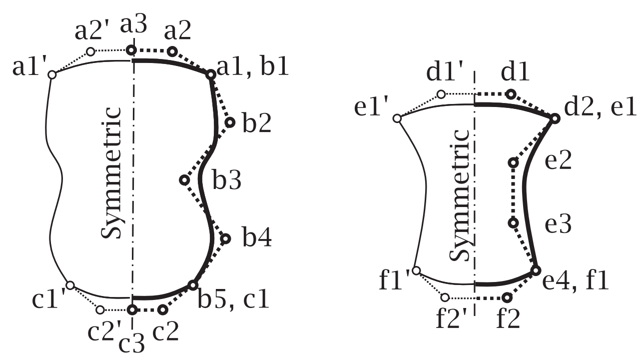

Figure 8. Control points of B-spline curves of a back (left) and seat (right).

Figure 9. 4-legged (left) and 5-legged (right).

As for preparation of questionnaire investigation, 11 words (Attractive, Brisk, Beautiful, Cool, Cute, Interesting, Original, Rich, Satisfactory, Stylish, Tender,) are selected as upper level kansei words, while 9 words (Comfort, Elegant, Fancy, Formal, Masculine, Mature, Sharp, Simple, Steady) are selected as middle level kansei words. 30 office chairs are prepared for questionnaire. These are

Figure 10. With armrests (left) and without armrests (right).

virtual model designed by using the above parameters. Their parameters are randomly configured.

As for subjects, 8 male undergraduate students participate as subjects. They belong to department of mechanical system engineering, electronics and information engineering or materials science and engineering. Since the proposed method is for a single customer, 8 experiments are carried out individually.

As for the setting of ANN, the network consists of 9 output nodes, 9 hidden nodes and 32 input nodes. The maximum number of iteration is 1000. As for the setting of GA, population is 30, mutation rate is 0.1 and terminal generation is 3000. Uniform crossover operator is used.

3.2. Results

8 subjects individually participate in the experiments and 8 office chairs are generated. Fig. 11 shows kansei space of

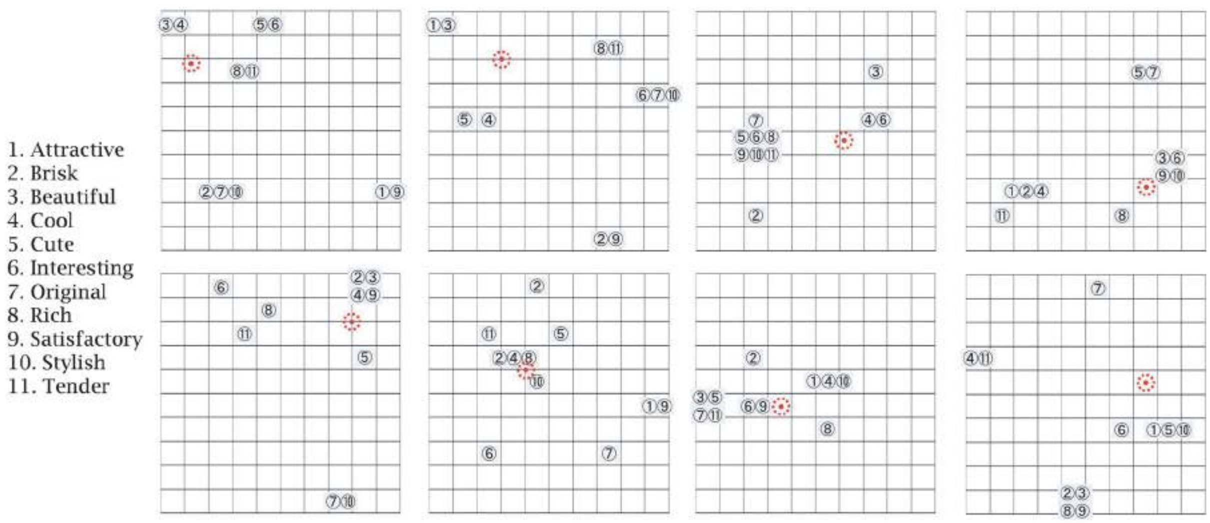

Figure 11. Kansei space of 8 subjects.

Figure 12. Generated design of office chairs.

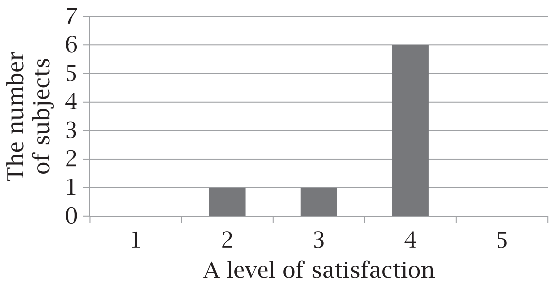

Figure 13. Evaluation of generated design.

subjects. Fig. 12 shows generated office chairs. After the experiment, they evaluate their own chairs on a scale of 1 to 5. Fig. 13 shows their evaluation results, which indicate the effectiveness of the proposed method.

And then, the case study of 8th subject is focused on and a series of its steps is described in detail. His kansei space and generated design are shown in the bottom right of Fig. 11 and 12. His evaluation score of generated design is 4.

Fig. 14 shows the histories of squared discrepancy between the expected output and the actual output in ANN and fitness function of GA. Since squared discrepancy becomes smaller than the threshold (< 0.0003), the optimization process finishes after 142 iterations. These histories show that their optimization processes are well converged. Tab. 1 shows the weight vectors of the design target obtained in Step3 and generated design which 8th subject evaluated after the case study. If the network constructed by ANN can precisely simulate the relationships between parameters of aesthetic elements and a weight vector of middle level kansei words, two weight vectors coincide with each other. Tab. 1 shows that the weights of "Elegant" and "Formal" are quite different between the design target and the generated design but the weights of the other words are quite similar between them. These results show that the proposed method can generate the design which subjects like most.

4. Conclusion

To support aesthetic design, a new aesthetic design support method using a three-layer model and a kansei space is developed. A three-layer model consists of upper and middle level kansei words and aesthetic elements and shows their relationships. The model is constructed by analyzing questionnaire results (evaluation results of existing products and upper level kansei words using middle level kansei words) using SOM and ANN. A kansei space shows the similarity of upper level kansei words and helps a customer understand his / her implicit and complicated kansei and express his / her needs for a new product. Kansei space is also constructed by analyzing questionnaire results using SOM. A new design that best fits to the customer need is explored by using GA. In the case study, the proposed method is applied to office chair design and its effectiveness is confirmed.

Acknowledgment

This work was supported by JSPS KAKENHI [Grant Number 26870693].

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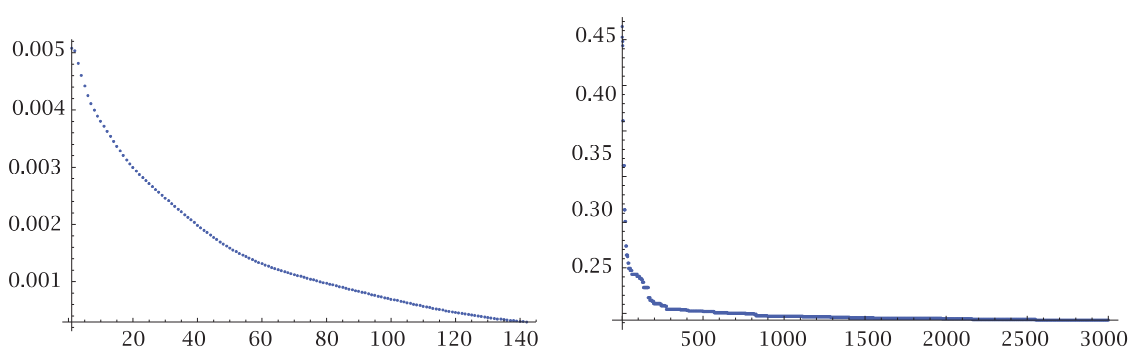

Figure 14. Histories of optimization processes in ANN and GA.

Table 1. Weight vectors of the design target and the generated design.

	Comfort	Elegant	Fancy	Formal	Masculine	Mature	Sharp	Simple	Steady
Design target	4.368	2.758	4.196	5.212	5.881	4.98	5.95	2.697	5.53
Generated design	5	5	3	2	6	6	6	3	6

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