Determining of Customer's Kansei Needs and Product Design Attributes by Rough Set Theory

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Abstract The trend of new product development taking into account a customer's feeling and needs has become very important for companies' development and competition in the market. Kansei engineering is a consumer-oriented technology that seeks to capture the voice of the customer to produce a successful product. This method helps to transform customers feeling into the design parameters. In order to improve customer satisfaction, it is very important to determine the design parameters that make up the product. This paper presents a design support system intended for use in designing new product. A product has a lots of design attributes. For this reason, the product design attributes are reduced with Rough sets theory and main design attributes are obtained for developing a new product. Rough sets theory deals with uncertain or conflicting data. After determining product design attributes, the different products are produced for evaluating customer's feel with Kansei adjectives. Customer evaluations were conducted using the semantic differential method to examine the relationship between users' assessments of product and design elements. Kansei results are analyzed by applied Principle Component Analysis to determine the relationships between products and emotions that affect the general preferences of customers. Baby cradle design is taken as a case study; but this method can be used to develop other products. As a result, this paper presents a design support system intended for use in designing new product, so the designed product can fit more closely to the consumers' desires.

Keywords Kansei engineering · Rough sets theory · Principle component analysis · Product design

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1 Introduction

An effective design can be defined not only the lowest possible cost and the shortest production time but also is able to entice consumer satisfaction so as to capture a large market share. The consumer-oriented design that is known as the consumer's satisfaction is a key role of market success in product development. Many manufacturers have realized the necessity for collaborating of their production capacity and customer needs for being successful in the market. Actually, customer needs and wants may change with time, so it is extremely difficult to maintain satisfaction of product. The design parameters of the product need to satisfy customer requirements for a product to be successful.

Kansei engineering is a well-known method that transform design elements into customer needs for capturing market successful. Kansei engineering is proposed by Mitsuo Nagamachi from Japan in 1970. Kansei engineering begins with a Kansei word which is the Japanese term, means customer's psychological feelings, sensations, and emotions [1]. This method can be used a large range of products from automotive sector to furniture sector.

To analyze association of Kansei to product design parameters, a various statistical techniques have been attempted such as multiple regression, the Quantification Theory type I (QT1), Fuzzy Logics, Neural Networks, Genetic Algorithm, Rough-Set Analysis and Partial Least Square Analysis. Hsiao used a fuzzy set theory to identify the relation between 15 car design styles and customer feelings by means of adjectival images words [2]. Lai et al. presented a new approach based on ANN and Quantitative Theory Type I to transform costumers' affective needs to product design forms and product color on mobile phones [3]. Quantitative Theory Type I was used to identify how product color and product design form can affect the product image of mobile phones. Poirson et al. implemented GA to identify the optimal product design form elements to improve the quality of musical instruments [4].

The creation of new design is a difficult task. Thus, market sales range is common topic for designers and manufacturers to decision in the development of new products. In this study, the evaluation of the designs in the market based on sales was conducted to identify the effective design parameters with Rough Sets Theory. Al-Mayyan et al. used Rough set approach for reducing set of nine features that were found to capture the essential characteristics required for signature identification [5]. Zhai et al. proposed a rough set based decision support approach to improving consumer affective satisfaction in product design [6]. After determining product design parameters, the alternative products were designed by designers. According to Kansei results, due to the different of customer needs, the principle component analysis was used to identify the basic customer needs in the market for help to designers.

The paper starts with the application of Rough sets theory method for choosing effective design parameters on present product sales in the market. Then, the designers derived different design alternatives from these design parameters. A various Kansei words were collected from internet, magazine and brochure, and were evaluated using an 11-point semantic scale. Finally, the principal component analysis is used as a method of determining customer feeling space with Kansei evaluation results.

1.1 Parameter Selection Using Rough Set

One of the important issues of the new product design is how settings of design parameters of new products. It can be determined from sales of present products in the market. Firstly, to achieve this, we need to model the relationship between sales of present products and design parameters.

The rough sets theory is proposed by Professor Pawlak for knowledge discovery in databases and experimental data sets [7]. It can be employed to extract concepts or decision rules from a given set of data and has been used successfully in many application domains [8, 9]. The rough set theory offers the benefits of efficiency, understandability, and results that can be interpreted directly [10].

In rough sets, an information system can be presented in the form of the decision table.

$$\mathrm{DT} = \{\mathrm{U}, \mathrm{R}\,(\mathrm{C} \cup \mathrm{D})\,, \mathrm{V}, \mathrm{f}\}$$

Assume that U is the universe containing all the alternatives which are registered in an information table. A data table is the 4-tuple S = (U, R, V, f) where U is a finite set of objects (universe); is a set of attributes, subsets C and D are the condition attribute set and the decision attribute set, respectively; is domain of the attribute r, and is a total function such that for each called information function [11].

To every non-empty subset B of attributes is associated an indiscernibility relation on U, denoted by:

$$IND\,(\mathrm{B}) = \{(x, y) \,/\, (x, y) \in UxU, \forall b \in B\; (b(x) = b(y))\} \tag{1}$$

Clearly, the indiscernibility relation defined is an equivalence relation (reflexive, symmetric and transitive). The family of all the equivalence classes of the relation IND(B) is denoted by U/IND(B).

Definition 1 Entropy H(P) of knowledge P (attributes set) is defined as

$$H\ (\mathrm{p}) = -\sum_{i=1}^{n} p\ (\mathrm{X}_i) \log p\ (\mathrm{X}_i) \tag{2}$$

where p(X_i) = |X_i |/|U| and p(X_i) denotes the probability of X_i when P is on the partition X = {X_1,X_2,X_3 ... X_n} of universe U, i = 1,2, ... ,n.

Definition 2 Conditional entropy H(Q/P) which knowledge Q(U/IND(Q)) = ({Y_1,Y_2, ... Y_n}) is relative to knowledge P(U/IND(P)) = ({X_1,X_2,X_3 ... X_n}) is defined as

$$H\ (\mathrm{Q/P}) = -\sum_{i=1}^{n} p\ (\mathrm{X}_i) \sum_{j=1}^{m} p\left(Y_j/X_i\right) \log p\left(\mathrm{Y}_j/\mathrm{X}_i\right) \tag{3}$$

where p(Y_j/X_i) is conditional probability, i = 1, 2, ... ,n, j = 1,2, ... ,m.

Definition 3 Suppose that decision table, subsets C and D are the condition attribute set and the decision attribute set, respectively, attribute subset. The attribute significance SGF(a, A, D) of attribute is defined as;

$$SGF\ (\mathrm{a, A, D}) = \mathrm{H}\ (D/A) - H\ (D/A \cup \{a\}) \tag{4}$$

Given attribute subset A, the greater the value of SGF (a, A, D), the more important attribute a is for decision D.

1.2 Determining Emotional Design Space Using Principle Component Analysis

The Principle Component Analysis (PCA) is a mathematical algorithm that is a linear combination of variables to access a compromised output with the purpose of reducing the data dimensions [12]. PCA aims to find a new set of dimensions that better captures the variability in multiple dimensions. The first dimension is chosen to capture as much of the variability as possible. The second dimension is orthogonal to the first, and, subject to that constraint, captures as much of the remaining variability as possible, and so on [13]. In other words, this process is to approach the maximum variance with respect to the distinctive features of data [14]. Further, it is effectively used to reduce the dimensions of data.

PCA is commonly used to find semantic space of Kansei and specimens, and Kansei strategy for designers could be determined by PCA results. Kansei strategy is important as it could be used by designer and manufacturer to determine new concept of product, with capturing a clue about customer emotional needs on product design. The Plot of PC loadings could be used to visualize how much the evaluation on Kansei affects variables, and the plot of PC Score shows which Kansei has strong relations to what specimen [15].

2 The Case Study

Kansei engineering methodology with a Rough sets and PCA is applied to determine design parameters and new product design area that related to customers' emotional needs for assisting product designers. To evaluate the method, the case study of baby cradle design was conducted. The steps of the method for application of Kansei Engineering with Rough sets and PCA are given as follows:

Step 1 Selection of a product.

The product is selected as a baby cradle because of the demand investigation (sales data), target users (parents) and the market share. Thus, baby cradle samples and sales data are collected from the market for this study.

Step 2 Identification of product's item & categories.

Product design are constituted from different design parameters. The baby cradle has 11 different design parameters such as legrest, front block, chest of drawers, back, headboard, bottom drawer, leg, colour, headboard-crown, UV press, handle. A legrest, front block, back and headboard are basic parameters of baby cradle. At the same time, each parameter has various categories. For example, the chest of drawers is investigated as not used, one cabinet, two drawer and three drawer.

Step 3 Definition of design parameters (decision rules) of the product for the decision of sales using Rough Sets methods.

The Rough set methods have been used to extract decision rules between sales data and design parameters. Parameters may be irrelevant that having no effect on the emotional design or relevant that having an impact on the emotional design. A design parameter may have a different discriminatory or predictive power. The sales data that was previously realized is used for the determining parameters. The sales data of the product to be designed are divided into two classes depending on whether the sales value is above or below the average sales value as a class 1 or class 2, respectively.

The data table was constructed with 7 design parameters and 22 different baby cradle to categorized response variables, meaning "1 = above or below the average sales value" and "2 = below the average sales value" values in Table 1.

Table 1 Decision table about design parameters

Baby cradle alternatives	Chest of drawers	Bottom drawer	Leg	Colour	Head board crown	Handle	UV press	Sales class
1	0	0	1	1	0	0	0	1
2	0	0	0	1	0	0	0	2
3	1	1	0	1	1	1	0	2
4	2	1	0	1	0	1	0	2
5	3	1	1	1	0	1	0	2
6	3	1	0	1	0	1	0	1
7	2	1	0	1	0	1	0	2
8	0	0	0	4	0	0	0	2
9	2	0	0	4	0	0	0	2
10	3	1	0	4	0	1	0	2
11	2	0	0	4	0	1	0	1
12	2	1	0	4	0	1	0	1
13	0	1	0	4	0	0	0	1
14	3	1	0	3	0	1	0	1
15	2	0	0	3	0	1	0	1
16	3	1	0	2	0	1	0	1
17	2	0	0	2	0	1	0	2
18	1	0	0	1	0	0	0	1
19	1	0	0	1	1	1	1	1
20	0	1	1	1	0	0	0	2
21	2	0	0	4	0	1	0	1
22	2	0	0	1	0	1	0	1

For the decision table of Table 1, we can get the significances of chest of drawers, bottom drawer, leg, colour, headboard-crown, handle, UV press by the following process:

$$\begin{aligned} &\mathrm{U/IND}\,\{chest\ of\ drawers, bottom\ drawer, leg, colour, headboard - crown,\\ &\qquad handle, uv\ press\}\\ &= \{\{1\}, \{2\}, \{3\} \ldots\ldots. \{12\}\}\\ &\mathrm{U/IND}\,\{\text{sales value}\} = \left\{\begin{array}{l}\{1, 6, 11, 12, 13, 14, 15, 16, 18, 19, 21, 22\},\\ \{2, 3, 4, 5, 7, 8, 9, 10, 17, 20\}\end{array}\right\}\\ &= \{\mathrm{D1}, \mathrm{D2}\}\\ &\mathrm{U/IND}\,\{bottom\ drawer, leg, colour, headboard - crown,\\ &\qquad handle, uv\ press\}\\ &= \{\{2, 8\}, \{10, 12\}, \{6, 7\}\}\\ &= \{\mathrm{X}_1, \mathrm{X}_2, \mathrm{X}_3\} \end{aligned}$$

$$P(X_1) = 2/22 P(D_1/X_1) = 1/2, P(D_2/X_1) = 1/2;$$

$$P(X_2) = 2/22 P(D_1/X_2) = 1/2, P(D_2/X_2) = 1/2;$$

$$P(X_3) = 2/22 P(D_1/X_3) = 1/2, P(D_2/X_3) = 1/2;$$

$$\text{SGF}\left(chest\ of\ drawers'', \{bottom\ drawer, leg, colour, headboard - crown, handle, uv\ press\}, \{D\}\right)$$

$$= \text{H}(\{D\} / \{bottom\ drawer, leg, colour, headboard - crown, handle, uv\ press\})$$

$$-\text{H}(\{D\} / \{chest\ of\ drawers, bottom\ drawer, leg, colour, headboard - crown, handle, uv\ press\})$$

$$= -\frac{2}{22}\left(\frac{1}{2}\log\frac{1}{2} + \frac{1}{2}\log\frac{1}{2}\right) \text{x3}$$

We obtain the significance of attribute "chest of drawers" as 0.0802, the significance of attribute "colour" as 0.1094, the significance of attribute "leg" as 0.0547, the significance of attribute "bottom drawer" as 0.032 and the significance of attribute "handle" as 0.0433, respectively. Headboard crown and UV-press are not obtained, because they are used one times in sales data sets. Thus, we do not take into account of them. Although, the design parameter of "colour" is seen the most important than others design parameter and affects the sales value, so "colour" which directly effects customer perception is not selected as design parameter. Except for basic parameters, the 3 parameters such as chest of drawers, leg and bottom drawer are selected for using new baby cradle design.

Step 4 Produce the design alternatives with decision rules.

According to Rough set results, seven parameters such that legrest, front block, chest of drawers, back, headboard, bottom drawer and leg are take into account for using new baby cradle design. The colour is not considered because of effect directly person's perceptions. 93 baby cradle alternatives are comprised by designer.

Step 5 Collection of Kansei words.

To determine new concept of baby cradle related to customer emotional needs and semantic space, the Kansei adjectives are collected from different sources such as magazines, articles, interviews with users, web sites of companies produce baby cradle, and marketing personnel of companies and product catalog. The 12 pairwise Kansei words that describe baby cradle were selected for use in this study. These 12 pairwise Kansei words that describe baby cradle were selected by a group composed with five experts who are academicians, furniture designers, from 80 Kansei words for use in this study because a larger set of adjectives might lead to decrease the reliability on the evaluation process. Table 2 shows the 12 Kansei adjectives that were most suitable for describing the baby cradle.

Step 6 Evaluation of product samples vs. Kansei words with Semantic Differential scales.

Table 2 The selected Kansei words

Modern-traditional	Charmless-cute
Ordinary-attractive	Poor quality view-quality appearance
Minimalist-decorative	Easy to clean-hard to clean
Feminine-masculine	Cheap-expensive
Romantic-adventurous	Indurable-durable
Useless-practice	Elegant-rough

Each adjective word such as modern-traditional, charmless-cute, ordinary-attractive, poor quality view-quality appearance, minimalist-decorative, easy to clean-hard to clean, feminine-masculine cheap-expensive, romantic-adventurous, indurable-durable, useless-practice, elegant-rough is evaluated using an 11-point semantic scale [16] by totally 384 volunteer subjects.

Step 7 Identification of the most representative Kansei Needs (customer emotional needs) of the market using PCA.

The PCA is used for reduction of customer emotional design space. The evaluated data on 93 baby cradle designs were analysed by PCA. The cumulative variance contribution rate is found % 84.531%. Three component is explained from Kansei data, the components 57%, 15.4%, 12.11%, respectively. Component 1 is grouped by the Kansei modern-traditional, ordinary-attractive, minimalist-decorative, charmless-cute, poor quality view-quality appearance, cheap-expensive, indurable-durable. Accordingly component 1 is named the 'Modern'. Component 2 is grouped by the Kansei feminine-masculine, romantic-adventurous, elegant-rough. Accordingly component 2 is named the 'Elegant'. Last component 3 is grouped by the Kansei easy to clean-hard to clean and useless-practice therefore named the 'Practice' component.

It is possible to show the PCA vector chart that illustrate each design alternatives and related to component 1 and 2. Figure 1 illustrates the PCA vector chart, which shows the positions of baby cradle alternatives on component 1 and component 2. This shows which samples are close to what Kansei. If there is a company strategy of Kansei concerning the next development Project a specific Kansei can be chosen. The resulting three components lead to a new baby cradle product and accordingly the designer is able to develop a new product applying these design points. Therefore, Kansei strategy is determined for baby cradle designer by PCA results. The emotional design knowledge extracted can be used to advise designers on the improvement of the product design towards higher affective satisfaction of consumers like in the study of Zhai [6]. The approach proposed is basic in implementation and can be easily applied to real industrial applications.

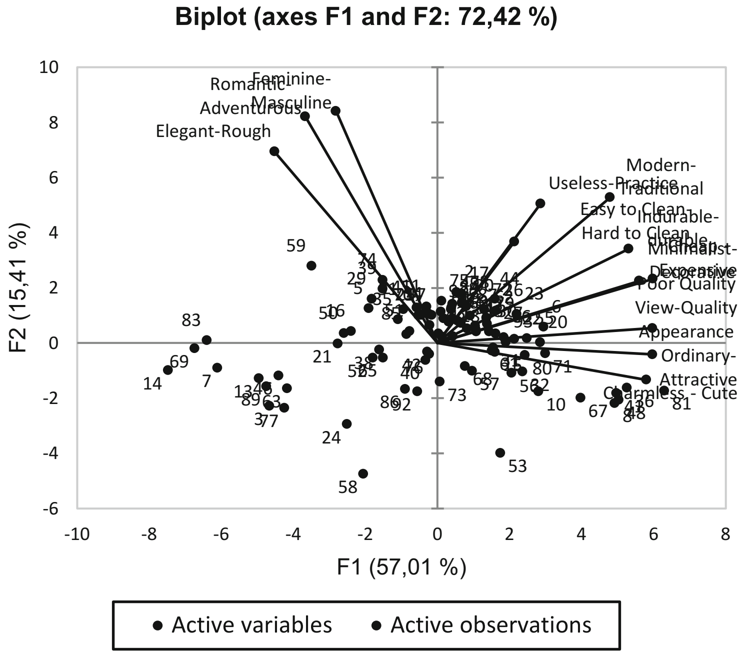

Fig. 1 PCA vector chart of components 1 and 2

3 Conclusion

Kansei Engineering is open to new models to translate more accurately the uncertain information of consumer feelings of a market to generate new product designs. In the present paper suggested the Kansei Engineering with Rough sets and PCA. With help of Rough sets, the product design parameters are determined and with help of PCA, Kansei strategy that comes from customer satisfaction needs is determined for product designer/engineer. We have applied proposed methodology to a new baby cradle design development. In the case study, a survey of 93 baby cradle was performed. The help of Rough Sets theory can be selected second degree design parameters that effect sales range for the design such as chest of drawers, leg and bottom drawer. Based on the survey results, the PCA was used to find emotional theme for relating customer satisfaction. We have determined which Kansei strategy are more important in terms of marketability for the baby cradle such as 'Modern, Elegant, Practice'. In future work, this Kansei Engineering methodology will be refined by applying it to more product development.

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