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Integrating the Kano model into a robust design approach to enhance customer satisfaction with product design

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ABSTRACT

The aesthetic qualities of products are critical factors in achieving higher customer satisfaction. This study presents a robust design approach incorporating the Kano model to obtain the optimal combination of design form elements. This can effectively enhance customer satisfaction and aesthetic product qualities with multiple-criteria characteristics. The Kano model is used to better understand the relationship between performance criteria and customer satisfaction, and to resolve trade-off dilemma in multiple-criteria optimization by identifying the key criteria in customer satisfaction. The robust design approach combines grey relational analysis with the Taguchi method to optimize subjective quality with multiple-criteria characteristics. This simultaneously yields the optimal aesthetic performance and reduces the variations in customer evaluations. Based on Kano model analysis, a weight adjustment process determines the weight of each product criterion for achieving the desired customer satisfaction performance. This process guides the prioritizing of multiple criteria, leading to higher customer satisfaction. A mobile phone design experiment was conducted to verify the benefits of using the proposed integrative approach. Results show that the generated optimal mobile phone design can effectively enhance overall aesthetic performance and customer satisfaction. Although mobile phone designs are the examples of this study, the proposed method may be further used as a universal robust design approach for enhancing customer satisfaction and product quality with multiple-criteria characteristics.

1. Introduction

Customer satisfaction is the major concern and prerequisite for competitiveness in today's global market. Because of market equivalence in product quality, the subjective quality of aesthetics is a critical determinant of customer satisfaction. For example, Apple's iMac was heralded as an "aesthetic revolution in computing". This indicates that the visual aesthetics of computers have become a factor in customer purchase decisions (Postrel, 2001). Related studies also concluded that the aesthetic quality of a design has a positive effect on customer satisfaction (Fynes and Búrca, 2005; Yamamoto and Lambert, 1994). Aesthetic design can enhance the desirability of a product and greatly influence customer satisfaction in terms of perceived product quality (Bloch, 1995). However, the relationship between subjective quality and customer satisfaction is seldom discussed (You et al., 2006; Yun et al., 2003). This study regards aesthetics as an aspect of quality and explores the impact of aesthetics on customer satisfaction.

Scientifically and efficiently enhancing the aesthetic quality of product design can be achieved by gauging customer responses to product aesthetics and correlating these perceptions to form elements. This enables researchers to modify designs and closer align them with

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customer needs (Coates, 2003). The customer-oriented Kansei engineering (Nagamachi, 2002) method is a tool for translating customer perceptions and feelings (Kansei in Japanese) into concrete form elements. This method has been successfully used to infer optimal product design (Chuang and Ma, 2001; Lai et al., 2006; Schütte and Eklund, 2005; You et al., 2006). Previous studies on Kansei engineering and aesthetics used questionnaire-collected data to examine customer subjective evaluations based on a mean scale rating. However, the evaluation of aesthetics is subjective and highly individualistic. Aesthetics evaluation based solely on mean scale ratings, without considering variation in customer evaluations, is not appropriate. Lai et al. (2005) presented a robust design approach to enhance quality perception by reducing the discrepancy between the actual customer feeling and the desired feeling and reducing ambiguity created by the highly individualized characteristics of the customers. The robust design approach focuses on bringing the mean closer to the desired target and simultaneously reducing quality variation. This design may be successfully used in subjective quality management.

Aesthetic experience has a multidimensional nature. Previous studies (Lavie and Tractinsky, 2004; Liu, 2003, Rashid et al., 2004; Schenkman and Jonsson, 2000) that used a one-dimensional construct (e.g., a semantic index "beautiful verse ugly" or a single aesthetic measure with Likert scale rating) to explain how users perceived subject quality are not appropriate. Optimizing aesthetic quality should be considered a multiple-criteria problem. Thus, multiple-criteria decision making is required. Usually these criteria are not equivalent, i.e., they make different contributions to the integral quality assessment. Some criteria are even competitive, i.e., an improvement in one criterion will inevitably lead to deterioration in another (Dimova et al., 2006; Chen et al., 2006). However, most studies (Bottani and Rizzi, 2008; Partovi, 2007; Wang et al., 2007) on multiple-criteria optimization employed weight determination methods to reflect how customers prioritize their wants without considering these features. The relationship between product criteria and customer satisfaction has mostly been assumed to be linear—the higher the perceived criteria quality, the higher the customer's satisfaction and vice versa. However, from the viewpoint of current theory, this relationship may be non-linear. Continuous improvement in some criteria, without considering what customers actually desire, may not be sufficient to enhance satisfaction. Conventional weight determination methods may not be able to completely illustrate the relationship between quality criteria and customer satisfaction levels. Understanding the relationship between certain quality criteria and customer satisfaction is necessary to decide which criteria to offer. Kano et al. (1984) developed a two-dimensional (linear and non-linear) quality model to address linear quality model shortcomings. This two-dimensional model divides quality criteria into must-be quality, one-dimensional quality and attractive quality. These terms describe a product's effect on customer satisfaction with or without a specific quality. The Kano model is an effective tool for categorizing product criteria and product requirements. Based on the Kano classification, the criterion with the greatest influence on customer satisfaction, i.e., the attractive quality, should be offered if two criteria cannot be promoted simultaneously due to technical or financial reasons. This method provides valuable guidance in trade-off situations during the product development stage (Conklin et al., 2004; Huiskonen and Pirttilä, 1998; Matzler and Hinterhuber, 1998). Accordingly, a design team can determine which areas should be targeted to produce maximum benefits in customer satisfaction. This study investigates the possible integration between a robust design approach and the Kano model for achieving higher customer satisfaction and the effectively optimizing multiple criteria.

Another purpose of this study is to explore aesthetic criteria characteristics and apply the Kano model to investigate the different impacts of criteria quality on customer satisfaction. An integrative method combining the Kano model with the robust design approach is proposed to enhance the subjective quality of aesthetics and customer satisfaction. The robust design approach combines grey relational analysis (GRA) and the Taguchi method (TM) into a grey-based TM (Lin and Lin, 2002; Tarng et al., 2002; Wang and Tong, 2004). We adopted this method to explore the relationship between design parameters and quality performance with multiple-criteria considerations. It also determines the optimal combination of design parameters to maximize quality performance and minimize quality variation. We adopted the Kano model to explore the relationship between multiple aesthetic criteria and customer satisfaction, and to identify the key factors that enhance satisfaction. The Kano classification results determined which aesthetic criteria should be emphasized to achieve higher satisfaction and optimize trade-offs between multiple criteria. Each criterion's effect on customer satisfaction was considered in the grey-based TM to effectively optimize aesthetic quality and customer satisfaction. We conducted an experimental study on mobile phone design to illustrate how the Kano model can be integrated into the robust design approach and to verify the effectiveness of the proposed method.

2. Theoretical background

2.1. Robust design approach for multiple-criteria optimization

Robust design is a quality improvement engineering method that seeks the lowest cost solution to product design specifications based on customer requirements. The TM is the conventional approach to achieve robustness (Cabrera-Rios et al., 2002). The primary tools of the TM are orthogonal arrays (OAs) and the signal-to-noise (S/N) ratio. The former substantially reduces the number of required experiments and the latter simultaneously finds the most robust combination and the best possible performance (Taguchi and Clausing, 1990). The TM defines a loss function to calculate the deviation between the experimental value and the desired value. The value of the loss function is further transformed into a S/N ratio. S/N ratio analysis usually considers three performance characteristic categories: lower-the-better, higher-the-better and nominal-the-better. The S/N ratio for each design parameter level is computed based on S/N analysis. Regardless of the performance characteristic category, a larger S/N ratio corresponds to a better performance characteristic. Therefore, the optimal design parameter level is the level with the highest S/N ratio. In most industrial applications, the TM is used to solve problems with a single performance characteristic. In the real world, however, most products require more than one quality characteristic to be considered simultaneously, i.e., most of the problems that customers encounter involve multiple criteria. Optimizing multiple performance characteristics is much more complicated than optimizing a single performance characteristic (Korpela et al., 2007; Nearchou, 2006). A design with a higher S/N ratio for one performance characteristic may produce a lower S/N ratio for another performance characteristic. As a result, an overall evaluation of S/N ratios is required to optimize multiple performance characteristics. This study adopts a grey-based TM (Lin and Lin, 2002; Wang and Tong, 2004), which combines GRA with the TM, to solve this problem.

The grey system theory developed by Deng (1982) is an effective mathematical means to deal with system analysis characterized by incomplete information. The GRA method, in grey system theory, measures the relationship between factors based on their degree of similarity in development trends (Deng, 1982). More precisely, during the system development process, if the trend for the change between two factors is consistent, it produces a higher grey relational grade (GRG). The GRA method can effectively solve complicated inter-relationships between multiple performance characteristics.

The GRA calculation process in the grey-based TM is briefly reviewed. In GRA, data preprocessing is first performed to normalize the raw data for analysis. A linear normalization of the S/N ratio is performed in the range between zero and unity, which is also called grey relational generating (Deng, 1989). The data are transformed into the normalized data in the following three situations (Lin and Lin, 2002):

1. Measuring the effectiveness of the lower-better

$$x_{ij} = \frac{\max_j \eta_{ij} - \eta_{ij}}{\max_j \eta_{ij} - \min_j \eta_{ij}} \tag{1}$$

2. Measuring the effectiveness of the higher-better

$$x_{ij} = \frac{\eta_{ij} - \min_j \eta_{ij}}{\max_j \eta_{ij} - \min_j \eta_{ij}} \tag{2}$$

3. Measuring the effectiveness of the nominal-better

$$x_{ij} = \frac{|\eta_{ij} - \eta_{\text{ob}}|}{\max\{\max_j \eta_{ij} - \eta_{\text{ob}}, \eta_{\text{ob}} - \min_j \eta_{ij}\}} \tag{3}$$

where η_{ij} is the S/N ratio for the performance of the ith criterion in the jth experiment (design) and x_{ij} is the normalized S/N ratio; η_{ob} is the target value and $\min_j \eta_{ij} \leqslant \eta_{\text{ob}} \leqslant \max_j \eta_{ij}$.

The grey relational coefficient is calculated from the normalized S/N ratio to express the relationship between the desired and the actual normalized S/N ratio. The grey relational coefficient ξ_{ij} for the ith performance characteristic in the jth experiment (design) can be expressed as

$$\xi_{ij} = \frac{\min_i \min_j |x_i^0 - x_{ij}| + \zeta \max_i \max_j |x_i^0 - x_{ij}|}{|x_i^0 - x_{ij}| + \zeta \max_i \max_j |x_i^0 - x_{ij}|} \tag{4}$$

where x_i^0 is the ideal normalized S/N ratio for the ith performance characteristic and $\zeta \in [0,1]$ is a distinguishing coefficient for controlling the resolution scale, usually assigned with the value of 0.5.

A weighting method is then used to integrate the grey relational coefficients of each criterion into the GRG to reflect the importance of each criterion. Many methods can be used to determine weights (Hwang and Yoon, 1989), including the eigenvector method, entropy method, analytic hierarchy process, etc. The overall evaluation of the S/N ratio of multiple performance characteristics (i.e., the GRG) is based on the following equation:

$$\gamma_j = \sum_{i=1}^{n} W_i \xi_{ij} \tag{5}$$

where γ_j is the GRG for the jth experiment, W_i is the weight for the ith criterion, $i = 1,2,\ldots,n$, n is the number of criteria and $w_i = [0,1]$ satisfies $\sum_{i=1}^{n} W_i = 1$.

As a result, optimizing complicated multiple performance characteristics merely requires optimizing a single GRG. The optimal combination of design parameters is the one with the highest GRG. Furthermore, a statistical analysis of variance (ANOVA) or a quantitative theory type I analysis can specify which design attributes are statistically significant in affecting the GRG. With GRA, ANOVA or quantitative theory type I analysis, the optimal combination of design attributes can be predicted. The TM combined with GRA can greatly simplify optimization procedures for determining optimal parameters for multiple performance characteristics.

To resolve the complicated problem of multiple-criteria optimization, a weighting method is usually used to determine the importance of each criterion on affecting perceived quality in the grey-based TM. However, criteria weights only reflect how customers prioritize their wants, and cannot illustrate the relationship between customer satisfaction and product criteria. To effectively achieve the desired customer satisfaction, a design team should know what the customer wants most and also understand how much attention to pay to each product criterion. The authors of this study propose a process model to adjust criteria weights by incorporating the Kano model to achieve the highest customer satisfaction.

2.2. *Kano model of customer satisfaction*

Customers evaluate the quality of a product using several factors and dimensions. Therefore it is important to identify which product criteria or attributes create more satisfaction than others. Kano et al. (1984) developed a two-dimensional model to explain the different relationship between customer satisfaction and product criterion performance. The Kano model classifies product criteria into three distinct categories, as shown in Fig. 1. Each quality category affects customers in a different way. The three different types of qualities are explained as follows:

1. *The must-be or basic quality*: Here, customers become dissatisfied when the performance of this product criterion is low or the product attribute is absent. However, customer satisfaction does not rise above neutral with a high-performance product criterion.
2. *One-dimensional or performance quality*: Here, customer satisfaction is a linear function of a product criterion performance. High attribute performance leads to high customer satisfaction and vice versa.
3. *The attractive or excitement quality*: Here, customer satisfaction increases superlinearly with increasing attribute performance. There is not, however, a corresponding decrease in customer satisfaction with a decrease in criterion performance.

Besides these three, two more quality types can be identified: the indifference and reversal qualities (to be precise, they should call them characteristics because they are not really a customer need). For the indifference quality, customer satisfaction will not be affected by the performance of a product criterion. For the reversal quality, customers will be more dissatisfied with the increase of a criterion performance.

A simple way of identifying different Kano categories, one-dimensional, attractive and must-be qualities, is to use a Kano questionnaire (Kano et al., 1984). In this questionnaire, customers indicate if they feel satisfied or dissatisfied with a given situation. First, a situation supposes the quality (criterion) is present or sufficient. The customer must choose one of the following answers to express his feelings:

a. Satisfied
b. It should be that way
c. I am indifferent
d. I can live with it
e. Dissatisfied.

A second situation assumes the quality is absent or insufficient. Again, the customer must choose one of the above-mentioned feeling responses. By combining the two answers in the Kano evaluation table (Table 1), the product criterion can be identified as attractive, must-be, one-dimensional, indifference or reversal.

Matzler and Hinterhuber (1998) showed that the advantage of using the Kano model to classify customer requirements is a better understating of product requirements. This permits designers to focus on priorities for product development. It is, for example, not very useful to invest in improving must-be qualities that have already reached a satisfactory level. It would be better to improve one-dimensional or attractive qualities because they have a greater impact on perceived quality, and consequently, on customer satisfaction. Kano classification also provides valuable help in case of a trade-off situation in multiple-criteria decision making. If two product criteria cannot be promoted simultaneously due to technical or financial reasons, the criterion with the greater influence on customer satisfaction should be enhanced first. The Kano model can also be used to establish the importance (weight) of individual product criterion in multiple-criteria decision making, and thus create the optimal perquisite for product development activities. Tan and Pawitra (2001) presented an integrative approach involving the Kano model and quality function deployment (QFD). The Kano model adjusts the improvement ratio for re-prioritizing attributes in the QFD method. The integrative approach provides a basis for deciding the relative priority of improving product attributes based on Kano categories. However, it cannot illustrate how to design and improve product quality to meet customer requirements. In the study, the Kano model is integrated into the robust design approach to infer the optimal design parameters for achieving the highest customer satisfaction.

3. A proposed integrative approach for customer satisfaction

An integrative approach is proposed to better understand the relationship between customer satisfaction and

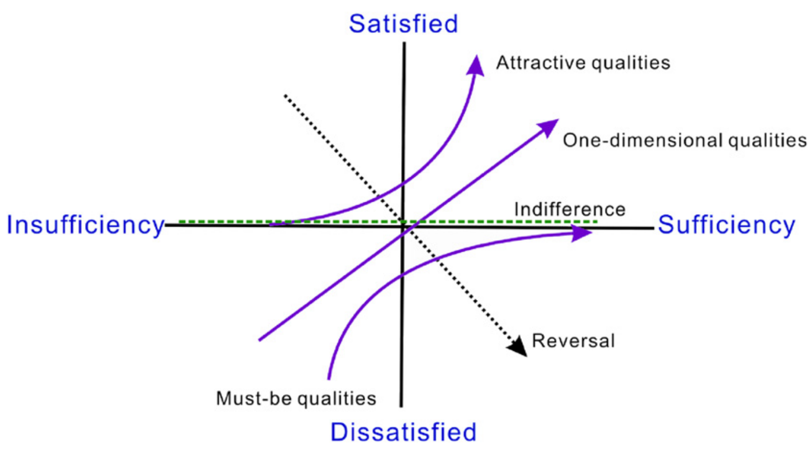


Fig. 1. Kano model of customer satisfaction.

Table 1
Kano evaluation table

Product criteria/attributes		Insufficiency				
		Satisfied	It should be that way	I am indifferent	I can live with it	Dissatisfied
Sufficiency	Satisfied	Q	A	A	A	O
	It should be that way	R	I	I	I	M
	I am indifferent	R	I	I	I	M
	I can live with it	R	I	I	I	M
	Dissatisfied	R	R	R	R	Q

A—attractive, O—one-dimensional, M—must-be, I—indifference, R—reversal, Q—questionable.

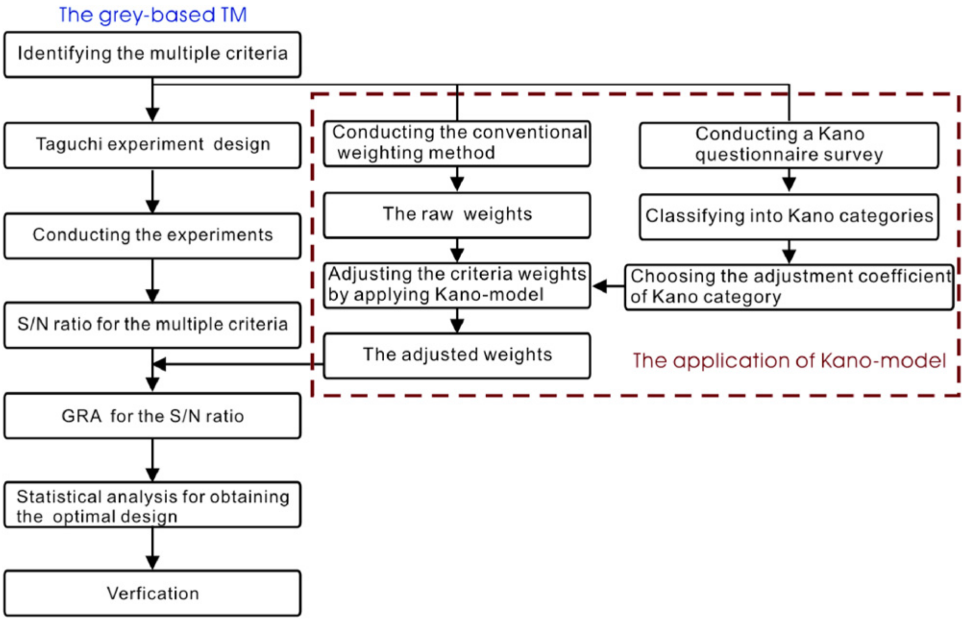


Fig. 2. The proposed integrative approach of this study.

product criteria, and to obtain the optimal design attribute combination of the multiple-criteria optimization in this study. Fig. 2 outlines the proposed approach using the Kano model and the grey-based TM.

Multiple criteria affecting perceived product quality should first be identified. The conventional weighting method is used to obtain the raw weights of criteria. The Kano model differentiates how well the criteria are able to affect customer satisfaction. A Kano questionnaire helps categorize criteria related to consumer satisfaction into different types of qualities and indicates how much attention should be paid to each product criterion to achieve the desired customer satisfaction. Logically, the criteria in the attractive category should receive attention first. Criteria in the one-dimensional and must-be categories should receive successively lower priorities. A weight adjustment method based on the Kano classification is used to re-prioritize the criteria in this study. The process of adjusting criteria weights is also shown in Fig. 2.

The first step of the weight adjustment process is to identify the proper Kano category for each criterion related to consumer satisfaction based on the Kano questionnaire results. The purpose of this is to magnify the weights of higher-return criteria in increasing customer satisfaction and resolving the trade-off situation of multiple-criteria optimization. Raw weights obtained in the conventional weighting method were then adjusted by multiplying with the adjustment coefficient (K) for each Kano category. Values of “4”, “2”, “1” and “0” were assigned to the attractive, one-dimensional, must-be and indifference categories, respectively. The weight adjustment can be expressed as

$$w_{i\_\mathrm{adj}} = \frac{W_i K_i}{\sum_{i=1}^{n} W_i K_i} \tag{6}$$

where w_{i_adj} is the final adjusted weight for the ith performance criterion, W_i is the raw weight for the ith performance criterion, $i = 1,2,\ldots,n$, and K_i is the adjustment coefficient according to its Kano quality classification.

The key difference between the conventional weighting method and the method based on the Kano model is that the former represents the importance of customer requirements while the latter represents the importance of customer satisfaction. The final adjusted weights are then used as criteria priorities in the grey-based TM to better understand the customer needs and desires and effectively achieve customer satisfaction.

The grey-based TM was conducted to infer the optimization of design attributes. This includes the following steps:

Step 1: Identify the design attributes and setting levels for the Taguchi experiment design.

Step 2: Select an appropriate Taguchi's OA and assign the design attribute parameters to the OA. Then generate experimental samples based on the OA.

Step 3: Conduct the evaluation experiment for each sample on the identified criteria.

Step 4: From the experimental data, calculate the S/N ratio for each criterion performance.

Step 5: Perform GRA by combining the final adjusted weights based on the Kano model.

Step 6: Analyse the experimental results using the GRG and statistical analysis method.

Step 7: Select the optimal level of design attributes to obtain the optimization design and identify the significant attributes.

Step 8: Perform a verification experiment to confirm the design.

4. The proposed integrative method to optimize the aesthetics satisfaction of mobile phone design

This section presents a mobile phone case example to illustrate how the proposed approach can be used to optimize aesthetics satisfaction robustly.

4.1. Determining the aesthetic criteria of product design

Customer satisfaction with product aesthetics involves multiple criteria. It is important to identify the most important and representative aesthetic criteria to ensure efficiency. An appropriate set of criteria for aesthetics satisfaction was first collected through literature reviews (Liu, 2003; Rashid et al., 2004; Schenkman and Jonsson, 2000; Talia and Noam, 2004). Six experts, senior designers with an average design experience of more than 10 years in the product design field, participated in focus groups (Nielsen, 1993) to identify the proper aesthetic criteria of product design. These experts identified aesthetic criteria including originality, unity, completeness, pleasure, simplicity and satisfaction of form.

4.2. Determining the design attributes of a mobile phone

The product form attributes that elicit customers' aesthetic perception were defined as the control factors in the current Taguchi experiments. Related literature on Kansei engineering for mobile phone design (Chuang et al., 2001; Lai et al., 2005; Yun et al., 2003) was first reviewed to identify the appropriate design attributes of mobile phones. Then, existing mobile phones were collected to identify commonly used important design attributes. The six experts were then asked to review the information and extract design attributes using morphological analysis (Zwick, 1967). The design attributes that were thought most likely to influence aesthetics were identified. The identified design attributes were grouped into two types: form features and feature composition, and the compositional relationship among these features. Table 2 presents the 10 identified design attributes and their corresponding level setting. Design attributes A, B, C, D, E, F, G describe the form features of the mobile phone designs; design attributes H, I, J describe the feature composition. Related studies (Shao et al., 2000; Wu and Chuang, 2003) suggest that the screen, function button style and speaker receiver were not significant factors in aesthetics evaluation. These features were kept fixed and excluded from the design attributes setting.

4.3. Design of Taguchi experiments

The control factor array chosen for this case study had to accommodate 10 control factors (A–J in Table 2), including nine factors with four levels and one with two levels. The full factorial of this combination would have required up to 524,288 (2×4^9) samples. The use of an OA can effectively reduce the number of experiments necessary to determine the optimal design attributes combination in a product design. The experiment layout using a Taguchi's L' 32 ($2^1\times 4^9$) OA, as shown in Table 3, was used to design the Taguchi experiment in this study. The data of each experimental run in the orthogonal table were then converted to a computer image of mobile phone design for aesthetic criteria evaluation. The 32 experimental samples are shown in Fig. 3.

4.4. Experimentation

A total of 35 male and 25 female subjects ranging from age 18 to 24 were recruited for the evaluation experiment. The subjects were asked to evaluate the 32 experimental samples on each of the six aesthetic criteria with a 7-point Likert scale (from 1 = not at all to 7 = intensely so). A Kano questionnaire survey was then conducted to classify the aesthetic criteria into the Kano categories. Table 4 shows the experimental results, the mean and the standard deviation (*S.*) of the evaluation of each sample on the six aesthetic criteria. The higher-the-better performance characteristic was assumed for these aesthetic criteria. The higher-the-better S/N ratio of each criterion for each sample was calculated for each criterion evaluation basis, i.e.,

$$\text{S/N (Higher-the-better)}\eta_{ij} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_{ijk}^2}\right)\ \text{(dB)} \quad (7)$$

where η_{ij} is the S/N ratio of the ith performance criterion in the jth experiment (sample), n is the total number of subjects and y_{ijk} is the evaluation value of the ith criteria in the jth sample by the kth subject. Table 4 shows the S/N ratios.

Table 2
Design attributes and levels for mobile phone design used in this study

Parameters (Design attributes)		Level 1	Level 2	Level 3	Level 4
A	Body shape Style	Symmetry(A1)	Irregular(A2)	Rotational Symmetry(A3)	Taper form(A4)
B	Side Shape	Parallel Line(B1)	Raised Curve(B2)	Concave Curve(B3)	Compound Curve(B4)
C	Top Shape	Line(C1)	Small Radius(C2)	Middle Radius(C3)	Large Radius(C4)
D	Length and Width Ratio of Body	115/45(D1)	107/46(D2)	100/45.6(D3)	80/46(D4)
E	CornerType	Slightly rounded(E1)	Moderately rounded(E2)	Round(E3)	Bevel(E4)
F	Outline Division Style	Non(F1)	Bottom Division(F2)	Rim Division(F3)	Special Division(F4)
G	Number Button Shape	Triangle(G1)	Round(G2)	Square(G3)	Hexagon(G4)
H	Number Button Arrangement	Separated(H1)	Horizontal grouped(H2)	Vertical grouped(H3)	Integration(H4)
I	Outline of Number Buttons Area	Square(I1)	Special Form(I2)	Trapezoid(I3)	Round(I4)
J	Number Bottoms Alignment	Arc alignment(J1)	Straight alignment(J2)		

4.5. The Kano classification

Table 5 shows the results of the Kano questionnaire, which provided information for classifying criteria. The criteria of originality, pleasure and satisfaction of form can be considered attractive requirements; completeness can be considered a one-dimensional quality. On the other hand, simplicity can be classified as must-be quality that customers take for granted. Unity is not related to customer satisfaction, and it was classified as an indifference quality. As mentioned before, efforts should be directed toward the attractive and one-dimensional criteria. The Kano classification corresponding to each criterion was then integrated to adjust the criteria weights by multiplying the adjustment coefficient (K) with each Kano category in the next step.

4.6. Determining adjusted criteria weights using the Kano model

Assigning criteria weights is usually based on expert opinions, and may cause a subjective bias. This study

Table 3
Experimental layout using $L_{32}{}'$ $(2^1 \times 4^9)$ OA

Experiment no.	Level of form attribute									
	A	B	C	D	E	F	G	H	I	J
1	1	1	1	1	1	1	1	1	1	1
2	1	2	2	2	2	2	2	2	2	1
3	1	3	3	3	3	3	3	3	3	1
4	1	4	4	4	4	4	4	4	4	1
5	2	1	1	4	2	2	3	3	4	1
6	2	2	2	3	1	1	4	4	3	1
7	2	3	3	2	4	4	1	1	2	1
8	2	4	4	1	3	3	2	2	1	1
9	3	1	2	4	3	4	2	1	3	1
10	3	2	1	3	4	3	1	2	4	1
11	3	3	4	2	1	2	4	3	1	1
12	3	4	3	1	2	1	3	4	2	1
13	4	1	2	1	4	3	4	3	2	1
14	4	2	1	2	3	4	3	4	1	1
15	4	3	4	3	2	1	2	1	4	1
16	4	4	3	4	1	2	1	2	3	1
17	1	1	4	3	1	4	3	2	2	2
18	1	2	3	4	2	3	4	1	1	2
19	1	3	2	1	3	2	1	4	4	2
20	1	4	1	2	4	1	2	3	3	2
21	2	1	4	2	2	3	1	4	3	2
22	2	2	3	1	1	4	2	3	4	2
23	2	3	2	4	4	1	3	2	1	2
24	2	4	1	3	3	2	4	1	2	2
25	3	1	3	2	3	1	4	2	4	2
26	3	2	4	1	4	2	3	1	3	2
27	3	3	1	4	1	3	2	4	2	2
28	3	4	2	3	2	4	1	3	1	2
29	4	1	3	3	4	2	2	4	1	2
30	4	2	4	4	3	1	1	3	2	2
31	4	3	1	1	2	4	4	2	3	2
32	4	4	2	2	1	3	3	1	4	2

adopted the entropy weighting method (Zeleny, 1982), which rests on the bases of the criteria evaluating only, to objectively determine the raw weights of aesthetic criteria. The relative entropies of criteria regarded as a measurement of structural similarity determine the relative importance, i.e. the criteria weights. The criteria weight processing steps can be summarized as follows:

Step 1: Allow d_{ij} to be the S/N ratios for evaluation of the ith criteria in the jth experiment samples, $i = 1,2,\ldots,n$; $j = 1,2,\ldots,m$, then $D = (d_{ij})_{n*m}$ is the sample evaluation matrix. Assume that z_{ij} is the converted value via d_{ij}; it can be defined as

$$z_{ij} = \frac{d_{ij}}{\sum_{j=1}^{m} d_{ij}} \tag{8}$$

Step 2: The entropy of the ith criteria e_i can be measured using the following equation, where $c = 1/\ln(m)$ and $e_i > 0$:

$$e_i = -c \sum_{j=1}^{m} z_{ij} \ln z_{ij} \tag{9}$$

Step 3: Compute the objective weight of the criteria, where $E = \sum_{i=1}^{n} e_i$ and the weight of ith criterion can be calculated as

$$w_i = (1 - e_i)/(n - E) \tag{10}$$

Since unity was identified as an indifference quality based on the Kano classification results, it was excluded from this case for economic and efficiency considerations. The S/N ratios of the other five aesthetic criteria for each experimental sample formed the raw data for the entropy weighting calculation. The raw criteria weights were obtained through data processing using Eqs. (8)–(10). The Kano model was then integrated to adjust each criterion weight according to its Kano category. The final adjusted weights for aesthetic criteria, explaining prioritization related to customer satisfaction, were computed using Eq. (6). Table 6 shows results of the adjusted weight incorporating with the Kano model. These results imply that attractive qualities should be emphasized, such as originality, pleasure and satisfaction of form. Simplicity, which was categorized as a must-be quality, should be given a lower priority. The entropy weighting method, on the other hand, indicated that simplicity should be prioritized first and originality last.

4.7. Grey relation analysis

In GRA, data preprocessing was first performed using Eq. (2) to normalize the S/N ratios of the subjects' criteria evaluation. Next, the grey relational coefficient was

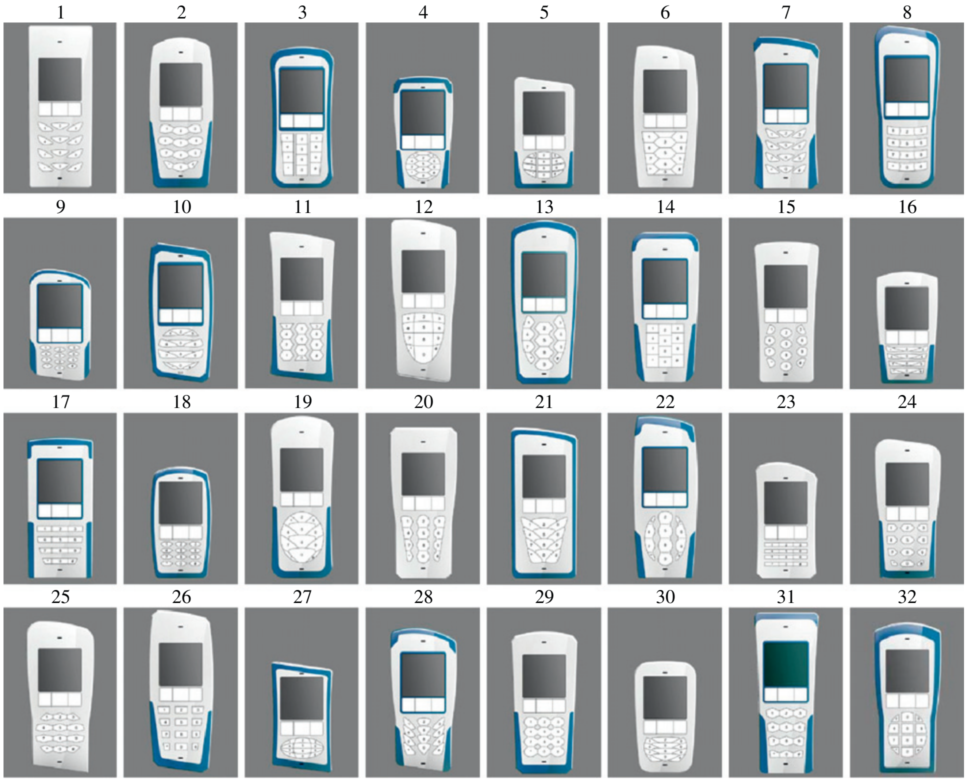


Fig. 3. Thirty-two mobile phones used in the current Taguchi experiment.

Table 4
Result of criteria evaluation in Taguchi experiments

No.	Simplicity			Originality			Completeness			Pleasure			Sat. of form			Unity		
	Mean	S.	S/N	Mean	S.	S/N	Mean	S.	S/N	Mean	S.	S/N	Mean	S.	S/N	Mean	S.	S/N
1	4.98	1.49	10.60	2.63	1.20	4.76	3.73	1.56	7.31	2.98	1.42	5.62	2.92	1.43	5.35	3.52	1.67	6.65
2	3.88	0.93	10.97	3.35	1.25	7.10	3.65	1.20	8.69	3.04	1.26	6.30	2.77	1.21	5.49	3.40	1.30	7.05
3	4.27	0.91	11.68	3.94	1.34	8.56	3.88	1.25	9.08	3.54	1.47	7.14	3.42	1.40	6.73	3.94	1.33	9.03
4	2.88	1.03	6.98	4.25	1.39	9.55	3.10	1.26	7.21	2.44	1.21	4.46	2.29	1.14	4.01	2.98	1.27	6.41
5	3.71	1.47	8.15	4.25	1.59	8.03	2.92	1.22	5.52	2.48	1.24	4.36	2.50	1.29	4.24	2.79	1.22	5.53
6	4.17	1.11	10.42	3.81	1.24	8.53	3.60	1.15	8.72	3.29	1.27	7.20	3.15	1.31	6.65	3.65	1.28	7.55
7	3.29	0.98	8.74	4.17	1.33	10.09	3.54	1.17	8.51	3.21	1.49	5.91	2.94	1.48	5.32	3.46	1.22	7.56
8	4.25	0.88	11.86	3.90	1.31	8.94	3.98	1.20	8.83	3.42	1.44	6.70	3.42	1.43	7.53	4.10	1.07	10.36
9	3.54	1.00	8.78	3.60	1.59	6.80	2.81	1.36	4.90	2.29	1.19	3.85	2.23	1.18	3.53	2.88	1.47	4.91
10	3.48	1.37	7.14	4.02	1.35	8.25	3.25	1.49	6.61	2.75	1.18	5.32	2.71	1.38	4.44	3.35	1.44	6.88
11	3.44	1.35	6.80	4.06	1.57	7.68	3.13	1.35	5.88	2.85	1.50	4.65	2.71	1.46	4.19	3.15	1.57	5.13
12	3.85	1.21	8.66	3.69	1.40	7.66	3.25	1.36	6.77	2.92	1.43	5.35	2.67	1.28	5.08	3.23	1.31	6.80
13	3.10	1.25	6.43	3.58	1.47	7.74	3.33	1.28	7.24	3.04	1.38	5.91	2.90	1.39	5.12	3.23	1.39	6.67
14	3.94	1.31	9.10	3.21	1.40	6.61	3.44	1.55	5.86	3.15	1.41	6.28	3.08	1.55	5.25	3.58	1.54	6.51
15	4.38	1.05	11.08	3.35	1.35	6.95	3.63	1.30	7.47	3.54	1.50	6.79	3.19	1.55	5.57	3.75	1.30	8.01
16	3.33	1.25	7.67	3.40	1.24	7.52	3.44	1.35	7.07	3.10	1.19	6.28	2.90	1.23	5.85	3.40	1.19	7.83
17	4.23	1.40	9.01	3.08	1.38	5.60	4.06	1.68	7.24	3.19	1.48	5.60	3.27	1.44	6.02	4.08	1.59	8.13
18	4.27	1.15	9.93	3.60	1.40	7.32	3.85	1.14	9.13	3.50	1.32	7.92	3.42	1.34	7.09	3.75	1.35	7.94
19	2.94	1.23	5.73	3.44	1.46	6.67	2.88	1.30	5.25	2.56	1.31	4.29	2.42	1.26	3.99	2.81	1.30	5.35
20	3.33	1.12	8.16	3.65	1.28	8.52	3.06	1.38	5.79	2.48	1.24	4.08	2.50	1.32	3.79	2.94	1.25	5.56
21	3.33	1.26	6.78	3.27	1.32	6.88	3.13	1.32	5.94	2.73	1.22	5.26	2.73	1.25	5.18	3.04	1.24	6.37
22	3.21	1.35	6.51	4.15	1.41	8.50	3.40	1.35	6.52	3.23	1.46	6.19	3.15	1.43	5.87	3.35	1.45	6.14
23	4.31	1.24	9.96	3.38	1.35	6.76	3.73	1.51	7.05	3.04	1.50	5.06	3.02	1.48	5.04	3.90	1.53	6.95
24	3.27	1.20	7.04	3.10	1.28	6.13	3.08	1.29	6.11	2.79	1.29	5.27	2.56	1.17	5.02	2.96	1.04	6.67
25	3.23	1.34	6.57	3.69	1.60	6.90	2.94	1.34	5.26	2.71	1.47	4.53	2.65	1.51	4.12	2.85	1.21	5.84
26	4.06	1.30	9.33	3.17	1.37	6.64	3.50	1.53	6.49	2.92	1.50	5.08	2.85	1.51	4.67	3.42	1.54	6.32
27	3.17	1.42	6.14	4.35	1.51	8.92	3.19	1.41	5.94	2.85	1.54	4.49	2.96	1.53	4.61	3.10	1.45	5.77
28	3.15	1.31	6.21	3.29	1.15	7.41	3.27	1.41	6.04	3.02	1.38	5.72	2.92	1.26	5.70	3.54	1.35	7.28
29	4.06	1.20	10.13	3.63	1.32	8.58	3.83	1.39	8.36	3.25	1.23	7.54	3.23	1.39	7.03	3.75	1.42	7.76

Table 4 (*continued*)

No.	Simplicity			Originality			Completeness			Pleasure			Sat. of form			Unity		
	Mean	*S.*	S/N	Mean	*S.*	S/N	Mean	*S.*	S/N	Mean	*S.*	S/N	Mean	*S.*	S/N	Mean	*S.*	S/N
30	4.02	1.51	8.16	3.60	1.37	7.65	3.77	1.52	7.45	3.48	1.59	6.41	3.54	1.58	6.45	3.81	1.56	7.10
31	3.44	1.35	7.42	3.67	1.49	7.73	3.35	1.45	6.12	2.81	1.42	4.67	2.81	1.45	4.80	3.42	1.51	6.20
32	3.81	1.38	8.45	3.58	1.34	8.05	3.60	1.55	7.16	3.10	1.46	6.31	3.17	1.53	6.08	3.52	1.51	7.06
MAX	4.98	–	11.86	4.35	–	10.09	4.06	–	9.13	3.54	–	7.92	3.54	–	7.53	4.1	–	10.36

Table 5
The Kano classification of aesthetic criteria

Criteria	A	O	M	N	R	Total (%)	Kano category
Originality	*50*	20	14	16	0	100	A
Unity	30	8	20	*38*	4	100	I
Completeness	28	*46*	8	16	2	100	O
Pleasure	*52*	30	14	4	0	100	A
Satisfaction of form	*64*	22	10	2	2	100	A
Simplicity	28	32	*38*	2	0	100	M

A—attractive, O—one-dimensional, M—must-be, I—indifference, R—reversal.

Table 6
Result of the determined criteria weights

	Simplicity	Originality	Completeness	Pleasure	Sat. of form	Unity
The adjusted criteria weights using Kano model						
Kano category	M	A	O	A	A	N
K	1	4	2	4	4	0
Raw weight	*0.271*	0.122	0.240	0.177	0.190	0
Adjusted weight	0.100	0.180	0.177	0.261	*0.281*	0
Conventional weighting method						
Entropy weight	*0.211*	0.087	0.178	0.181	0.173	0.170

calculated by Eq. (4), with the distinguishing coefficient $\zeta = 0.5$, to express the relationship between the ideal (best) and actual normalized S/N ratio of each design. Then, according to Eq. (5), the GRG (which was defined as the aesthetics index) was calculated by summing up the grey relational coefficients multiplied by the adjustment weight corresponding to each aesthetic criterion. An experimental sample with higher GRG has better performance in aesthetics satisfaction. Table 7 shows the grey relational coefficient and GRG for each experimental sample (design) using the L' 32 $(2^1 \times 4^9)$ OA. It shows that sample no. 8 has the best performance with multiple-criteria characteristics among the 32 samples because it has the highest GRG. In other words, optimizing complicated multiple performance characteristics can be converted into optimizing a single performance index, the GRG.

4.8. *Determining the optimal combination of design attributes*

The response of each form attribute level belonging to a design and the overall effect of each form attribute upon the performance index (GRG) was investigated using quantitative theory type I analysis. Quantitative theory type I (Nagamachi, 1989) is a multiple regression analysis technique for deducing the relationship between a quantitative variable (a dependent variable) and qualitative (nominal) variables (independent variables). Here, the dependent variable is the GRG of each experimental sample (phone design). The 10 independent form attribute variables (A–J) were represented one mobile phone design. Table 8 shows the quantitative theory type I analysis results.

In the last two rows of Table 8, *R* represents the correlation between the observed and predicted values of the dependent variable, and ranges from 0 to 1. The coefficient of multiple determination is R^2. This explains the linear relation between the independent variables (10 form attributes) and the dependent variable (GRG). The higher the R^2 value, the better the linearity between the dependent and independent variables. The partial correlation coefficients (PCC) indicate the relative importance of each of the 10 product variables (A–J) to overall aesthetics satisfaction. For example, the variable with the highest PCC is the “top shape” (PCC = 0.790), meaning that the top

Table 7
GRA aesthetics optimization results ($\zeta = 0.5$)

	Simplicity	Originality	Completeness	Pleasure	Sat. of form	GRG
Weight	0.100	0.180	0.177	0.261	0.281	
Ideal	1	1	1	1	1	1
1	0.715	0.335	0.572	0.478	0.478	0.493
2	0.779	0.473	0.847	0.565	0.495	0.600
3	0.946	0.637	0.979	0.731	0.714	0.775
4	0.393	0.833	0.558	0.379	0.363	0.489
5	0.459	0.566	0.402	0.372	0.378	0.423
6	0.686	0.633	0.856	0.746	0.694	0.724
7	0.503	1.000	0.797	0.512	0.475	0.639
8	*1.000*	*0.699*	*0.890*	*0.633*	*1.000*	*0.830*
9	0.506	0.449	0.364	0.341	0.333	0.379
10	0.401	0.593	0.491	0.447	0.393	0.461
11	0.384	0.527	0.427	0.392	0.375	0.417
12	0.496	0.525	0.507	0.450	0.449	0.478
13	0.367	0.533	0.562	0.512	0.454	0.494
14	0.533	0.435	0.426	0.562	0.467	0.485
15	0.801	0.461	0.594	0.651	0.505	0.580
16	0.429	0.510	0.540	0.562	0.543	0.530
17	0.525	0.374	0.563	0.476	0.570	0.504
18	0.620	0.492	1.000	1.000	0.820	0.820
19	0.340	0.440	0.385	0.367	0.361	0.379
20	0.460	0.631	0.420	0.354	0.348	0.425
21	0.383	0.455	0.432	0.442	0.460	0.442
22	0.370	0.628	0.482	0.550	0.546	0.533
23	0.624	0.446	0.538	0.424	0.445	0.474
24	0.395	0.404	0.445	0.443	0.444	0.432
25	0.373	0.457	0.386	0.383	0.370	0.392
26	0.555	0.437	0.479	0.426	0.412	0.446
27	0.355	0.696	0.432	0.380	0.406	0.451
28	0.358	0.500	0.440	0.489	0.522	0.478
29	0.645	0.640	0.759	0.847	0.799	0.760
30	0.460	0.524	0.590	0.582	0.650	0.580
31	0.415	0.532	0.446	0.393	0.423	0.438
32	0.480	0.568	0.552	0.567	0.580	0.559

shape of a mobile phone has the greatest influence on the perceived mobile phone aesthetics. The "corner type" (PCC = 0.078) is the least significant variable. According to the analysis, the "top shape" (PCC = 0.790), "body shape style" (PCC = 0.752), "outline division style" (PCC = 0.697) and "outline of number button" (PCC = 0.677) are the most significant design attributes affecting the aesthetics of a mobile phone. The category grades of a level indicate the effect of each form attribute on each level for aesthetics satisfaction. A positive grade indicates that this form attribute level can increase the perceived aesthetics of a mobile phone, while a negative grade should be avoided in product aesthetics. Based on the analysis, the optimal combination of form attributes, i.e. A2, B2, C3, D3, E2, F3, G2, H1, I1 and J1, is summarized in Table 9. A computer image of this optimized mobile phone design with the highest aesthetics satisfaction was constructed, as shown in no. 7 of Fig. 4.

4.9. Verification of improvement

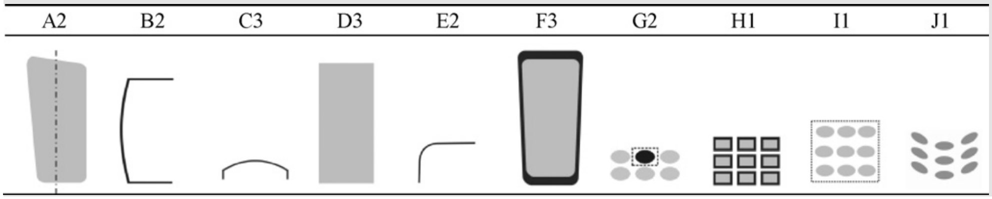
A confirmation test was then conducted to verify the performance of the optimized design generated using the proposed method. Six product design experts chose five mobile phones for competition. These phones are currently available or ready to enter the market. To provide an identical baseline for this evaluation, each sample (e.g. a real product) was transformed into a 2D image according to its specified form attribute level setting. The mobile phone form attributes including screen, function button style and speaker receiver were controlled to be the same as the samples used in our Taguchi experiment. The compared designs are shown in Fig. 4. An optimized design using the grey-based TM without applying the Kano model was also generated for comparison. In this aesthetics optimization case, the experimental data for the six aesthetic criteria and the weights for these six criteria were determined using the entropy weighting method, shown in Table 6. The optimal combination of form attributes for mobile phone design was found using GRA and the quantitative theory type I analysis, i.e. A4, B2, C3, D3, E1, F3, G3, H2, I1 and J1. The constructed image of this optimized design is shown in no. 6 of Fig. 4.

To conduct the competition evaluation, the same 60 subjects were asked to rank the seven samples on each of six aesthetic criteria and overall satisfaction with

Table 8
Quantitative theory type I results

Form attribute	Level	Category grade	PCC	Form attribute	Level	Category grade	PCC
A	A1	0.032	0.752	F	F1	−0.010	0.697
	A2	0.034			F2	−0.030	
	A3	−0.091			F3	0.076	
	A4	0.025			F4	−0.035	
B	B1	−0.043	0.598	G	G1	−0.028	0.487
	B2	0.053			G2	0.041	
	B3	−0.009			G3	−0.010	
	B4	−0.001			G4	−0.003	
C	C1	−0.078	0.790	H	H1	0.015	0.213
	C2	−0.017			H2	0.001	
	C3	0.087			H3	−0.013	
	C4	0.008			H4	−0.002	
D	D1	−0.017	0.619	I	I1	0.066	0.677
	D2	−0.034			I2	−0.006	
	D3	0.061			I3	−0.009	
	D4	−0.010			I4	−0.051	
E	E1	−0.002	0.078	J	J1	0.021	0.422
	E2	0.004			J2	−0.021	
	E3	0.003		Constant		0.528	
	E4	−0.005		$R = 0.931$	$R^2 = 0.867$		

Table 9
Optimal form elements of the mobile phone design for enhancing aesthetics



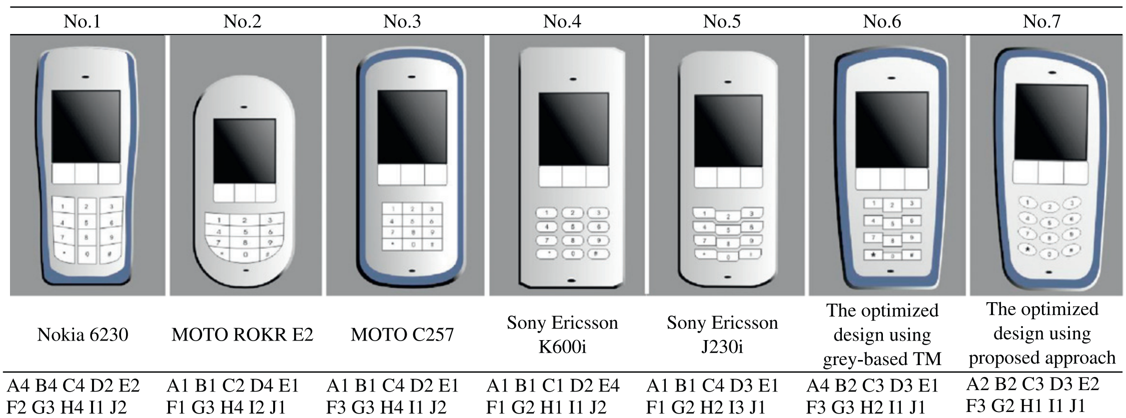


Fig. 4. Compared designs and the optimized designs for confirmation test.

a 7-point Likert scale (1 = not at all to 7 = intensely so). Confirmation test results were obtained for the means, standard deviations and S/N ratios of evaluations on each criterion and overall satisfaction. The optimal designs, nos. 6 and 7, exhibit smaller standard deviations for each of the criterion evaluation based on different weighting methods adopted in the robust design approach of the TM. Other non-optimized designs had significantly higher standard deviations. It can be concluded that the optimized design using the robust design approach consistently maintained a lower variation between consumer evaluations.

Table 10 shows that the performance of sample no. 7 (the optimized design generated by the proposed integrative method) in overall satisfaction and most of the aesthetic criteria were better than the compared designs. It obtained the highest evaluations on the attractive qualities of originality, pleasure and satisfaction of form. The obtained evaluations on completeness, simplicity and unity were moderate. The best performance in each criterion in the Taguchi experiment (shown in the second last row of Table 10) was also used as a reference for comparison with the optimized design. This result verified that the optimal combination of form attributes can effectively improve aesthetic quality with multiple-criteria characteristics, leading to higher consumer satisfaction.

Furthermore, GRA was conducted to compare the efficiency of these two optimized designs (nos. 6 and 7) on improving the overall S/N ratios. The GRG for each sample of the confirmation test was computed using the adjusted weights based on the Kano model and the entropy weights, as shown in Table 6. Table 10 shows the results of this analysis, and sample no. 7 was better than the compared designs because it obtained the highest GRG. The optimal design (no. 7), generated by the proposed approach, effectively enhanced attractive and one-dimensional criteria and properly offered the must-be criterion. It generated higher customer satisfaction than the optimal design computed without the Kano model. This confirmed the benefits of using the weight adjustment incorporated with Kano analysis to more accurately re-prioritize criteria improvement and resolve trade-offs in the multiple-criteria optimization problem.

A performance evaluation based on the ranking score (Feng and Wang, 2000) was also utilized to further investigate the validity of the proposed integrative method. Table 10 shows that the performance of each design in each criterion was ranked based on S/N ratio magnitude. The ranking of 1st, 2nd, 3rd, 4th, 5th, 6th and 7th then were scored with points 7, 6, 5, 4, 3, 2 and 1, respectively. The ranking score of each design in each criterion is presented in Table 11. Sample no. 7 was ranked 1st three times and 3rd three times, and its total score was 36 ($7 \times 3+5 \times 3 = 36$). Total score results for each design were computed, and are shown in Table 11. The optimized design no. 7 obtained higher scores than the compared designs and the other optimized design no. 6. It can be concluded that the proposed method of integrating the Kano model into the robust design approach is effective in simultaneously achieving aesthetic quality and overall satisfaction. Furthermore, a computer-aided design (CAD) system can use the optimization results to build a 3D model for facilitating the mobile phone design process, as shown in Fig. 5.

Table 10
Confirmation test results

No.	S/N ratio						Overall sat.	GRG	
	Simplicity	Originality	Completeness	Pleasure	Sat. of form	Unity		The adjusted weights	The entropy weights
1	10.55	10.41	10.94	11.73	12.22	*12.39*	11.36	0.70	0.74
2	12.13	7.23	11.43	10.33	8.22	9.37	9.67	0.53	0.59
3	11.25	9.91	*12.83*	11.67	10.18	11.77	11.95	0.67	0.73
4	*12.92*	7.07	10.46	7.78	7.34	9.34	9.67	0.47	0.57
5	11.50	11.98	9.73	10.70	8.60	10.97	10.75	0.55	0.59
6	12.72	11.71	12.44	11.55	11.98	12.22	12.72	0.78	0.84
7	12.36	*14.37*	12.33	*12.95*	*12.52*	12.01	*13.07*	*0.96*	*0.93*
The best performance in Taguchi experiment	11.86	10.09	9.13	7.92	7.53	10.36	–	–	–
Improvement in S/N ratio	0.50	4.28	3.20	5.03	4.99	1.65	–	–	–

Table 11
Result of the performance evaluations by the ranking score

No.	Performance order of each design in each criterion						Total scores
	Simplicity	Originality	Completeness	Pleasure	Sat. of form	Unity	
1	1	4	3	6	6	7	27
2	4	2	4	2	2	2	16
3	2	3	7	5	4	4	25
4	7	1	2	1	1	1	13
5	3	6	1	3	3	3	19
6	6	5	6	4	5	6	32
7	5	7	5	7	7	5	36

Fig. 5. 3D model of the CAD system.

5. Conclusion

This study uses a robust design approach that integrates the Kano model to optimize quality with multiple-criteria characteristics to achieve aesthetic satisfaction. The proposed robust design approach can be applied to objective and subjective quality, especially for multiple-criteria optimization. Hence, using the TM experimental design method requires only a small number of experiments, which saves time and money. Using the Kano model helps to differentiate between multiple criteria affecting customer satisfaction. It can also re-prioritize criteria to resolve the trade-off dilemma in multiple-criteria optimization. The application of this method was demonstrated with a case study on optimizing the aesthetics of mobile phones. It was verified that the Kano model presented advantages to better understand customer requirements, to identify the critical and high-return factors of customer satisfaction, and to resolve the trade-off dilemma in multiple-criteria decision making. This method improves the accuracy of criteria priorities determination. It can also be used to resolve existing problems in the current research on subjective quality, such as the Kansei engineering approach (Nagamachi, 1995; Nagamachi, 2002). The proposed method deals with the complicated inter-relationship between multiple criteria, reduces the variations existing between different customer evaluations and ensures accuracy with an economical and effective experimental design method. The results from this study provide useful insights for designing a mobile phone with optimal design attributes for enhancing aesthetics and overall customer satisfaction. The proposed robust design method integrated with the Kano model may be used as a universal method to simultaneously enhance customer satisfaction and product quality despite multiple-criteria characteristics.

A recommendation for future research in this integrative method is to define a means for more accurately representing and quantifying the information provided by the Kano model. The purpose would be to reduce ambiguity in criteria that straddle two categories. In addition to relationship analysis (linear and non-linear) between customer satisfaction and criteria performance, non-linear techniques such as neural networks could also be used in further studies.

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