ORIGINAL ARTICLE

Research into the Application of Kansei Engineering to the Modeling Aesthetic Design of a Numerical Control Machine Tool

Hong-Yi CHEN*, Jui-Che TU* and Kun-Chieh WANG**

* Graduate School of Design Doctoral Program, National Yunlin University of Science and Technology,
No.123, University Rd., Section 3, Douliou, Yunlin 64002, Taiwan

** Overseas Chinese University, No.100, Chiao Kwang Rd., Taichung 40721, Taiwan

Abstract: Facing the challenge of industry 4.0, the level of tool machinery must be promoted. Aesthetic appearance plays a crucial role in exhibiting the level of a machine. This paper introduces the grey-based Kansei engineering scheme in conjunction with an innovation process to provide a complete design process, from concept formulation to prototype making, so as to add the additional value of a machine. In this study, a computer-numerical-control (CNC) machine is chosen as the target since it ranks as high as the 3rd biggest enterprise in Taiwan. The CNC machine products in the marketplace were analyzed in two aspects: form decomposition and descriptive words. Then the Multiple Regression and Grey System Theory were applied to establish their relationship. Based on this relationship, the weight of each form element on a prescribed descriptive word can be obtained and used as design reference. With this reference, an image board of creativity can be established. A final innovative product form can be obtained by extracting the idea from this image board. Furthermore, a verification was performed and a satisfying result of the proposed Kansei-innovation manipulation procedure was obtained.

Keywords: Kansei engineering, CNC machine, Multiple regression analysis, Grey system theory, Innovative design

1. INTRODUCTION

1.1 Aesthetic of CNC machines

In recent years, Taiwan's machine tools have been exported in large quantities, and many advanced countries, such as the USA, Japan, Germany, and some new emerging countries, such as China, India, Brazil, Thailand, etc., have heavily adopted Taiwan's components to reduce costs and increase quality. With the exception of Japan and Germany, Taiwan has become the globally leading supply base for the components of as well as whole machine tools. However, there exists a big difference in the integrated design energy between Taiwan's CNC machines and European or American brands (Figure 1).

As known, a direct way to enhance the value of a CNC machine is the aesthetic form design of its appearance. A famous scheme called Kansei engineering can be used

to perform the form design, in which it was successfully used in product form design in many aspects.

1.2 Kansei engineering

In 1995, Kansei engineering was firstly defined by Nagamachi as "translating technology of a consumer's feeling and image for a product into design elements. This technique has some advantages over the other above-mentioned techniques and is still popular today [7]. Firstly, KE uses "word" to describe customer's feeling about a product. It is very easy to describe by every customer through questionnaire survey. Secondly, KE builds a quantitative relationship between emotional preferences of customer and design characteristics of product. This is very useful to provide an evaluation of how good a product is or how much extent of the product matching customer preferences. As such, a great amount of successful studies concerning this issue using Kansei engineering [13, 17, 18, 20] were proposed in the past.

Kansei Engineering has the following 5 different kinds of forms and implementation methods according to the differences of implemented design items and analysis direction [1].

1) Category Classification:

This classification method means that a series of concepts are extended and spread in the products' Kansei category, until the required design details are developed (Figure 2).

Figure 1: The left figure shows Taiwan's CNC machines; the right figure shows the globally famous brand, the DMG CNC machine.

Remarks: in order to conform to the research theme, this research focuses on the design adjectives of the numerical control machine tool in terms of practical technology and physical characteristics.

Figure 2: Hierarchy classification method of Kansei Engineering

2) Kansei Engineering Computer System, KES:

With the application of a computer system, a knowledge base of feeling and design elements is constructed to link the corresponding relationship of design elements, which is the pattern known by the public and has the most extensive application level in Kansei Engineering (Figure 3) [10].

3) Hybrid Kansei Engineering System:

The Hybrid Kansei Engineering system is the new implementation model of Kansei Engineering, as developed after revisions and improvements, and combines the positive and negative Kansei Engineering systems to construct a system model that can be used for communication between designer and user (Figure 4) [14].

Figure 3: Information system framework of Kansei Engineering

Figure 4: Hybrid Kansei Engineering system framework (Matsubara and Nagamachi, 1999)

4) Kansei Engineering Modeling:

This is to express the relationship between Kansei vocabularies and design elements with the application of mathematical modeling, and is the Kansei Engineering modeling of mathematical modeling (Figure 5) [2].

5) Virtual Kansei Engineering:

Virtual Kansei Engineering inspects whether design contents conform to actual demands through a virtual Kansei space; during the process, if the partial design contents require changes, designers can modify partial component contents of the framework according to demand (Figure 6).

Figure 5: Mathematical modeling application system framework of Kansei Engineering

Figure 6: Virtual Kansei Engineering framework system

Literature review shows that Kansei Engineering technology discusses how to transfer consumers' imagined feelings towards a product into the technology of its design elements, in order to achieve the communication of product aesthetics concepts and images through scientific analysis methods; it is applicable to almost all industrial design fields, including the design of the CNC machine tools. Accordingly, here we choose the Kansei Engineering IV as a part of methodology.

Furthermore, the Kansei engineering deals with past information about products. It lacks a bridge to communicate with the already-known data with the future products that possibly meet customers' requirements. Most important, we need a method to introduce creativity into the design procedure for a future product [5].

1.3 Creative thinking

The importance of creative thinking is emphasized in the design of teaching, and is a necessary process for the generation of creative designs, as it considers how to lead fantasy to the logical world; it can be described as a combination of inspiration, true feeling, contingency, and system [2].

In terms of the designer, "IDEA" is the source of originality, thus, "IDEA development" is also called "creativity development". In the case of the development of the left and right brain, in recent years, experts' continuous research shows that "creativity" begins from right brain (imagination, inspiration, and contingency) and then, it is generated via the left brain (logic, true feeling, and system), as shown in Table 1.

Regarding the academic research and development of creative thinking, humans continuously try to apply this magical creativity to the solution of various problems; according to research, the contents of each level are initiated from the thinking operation; thinking contents to thinking results. Thus, Roukes proposed the 3 Rs cycle model of creative thinking, as shown in Figure 7 [16].

During the completed product development process, the generation of ideas is often the most time-consuming and

Table 1: Creativity development system

Creativity	
Divergent thinking of right brain (sensibility)	Convergent thinking of left brain (rationality)
Parallel, expansion, replacement, restructuring, reverse direction, imagination	Analysis, integration, comparison, induction, deduction and observation

Figure 7: 3 Rs model of creative thinking

laborious part; therefore, according to literature, the development of creativity can be divided into a series of stages: "problem finding", "generation of idea", "evaluation of idea", and "problem solving" for implementation. Designers are "guided" and "enlightened" in the creativity development of modeling through knowing the Kansei factors of products' modeling aesthetics from Kansei Engineering.

Another effective way to generate the idea of a product form is the so called "product image board." A "product image board" collects the state-of-the-art of the possible related products which exhibit specified form concepts. Using the product image board, one may easily assemble or extract the different design elements to create a new concept meeting customers' requirements [2].

The image symbol design contains three stages: association, transformation, and concretization [3]. Following the manipulation of these three stages, designers may convert the product image into solid design elements/symbols.

2. RESEARCH STRUCTURE AND METHOD

The framework of this research is as shown in Figure 8. The research background, motivation, and goal are recognized first. The research theoretical basis is confirmed through literature collection, and then the target product of the CNC machine is analyzed through Kansei Engineering. The

Figure 8: Research framework diagram

Multiple Regression Analysis and Grey Theory are applied to establish the mathematical modeling for the relationship between the design elements and Kansei vocabularies. Further, design references are extracted from the results of Kansei model for a specified product image. With the manipulation of creative image board, the innovative design elements as well the whole form of a CNC machine can be built. After completion of the practical design, a survey on design satisfaction is conducted to establish the validity and reliability of the proposed methodology.

2.1 Method of Kansei Engineering IV

- 1) Selection of adjective vocabularies and design elements: The main purpose of this stage is to select the Kansei adjective vocabularies that represent the modeling aesthetic design of the numerical control machine tool, in order to understand people's significance and requirements for a numerical control machine tool; another purpose is to decompose all the design elements from the selected samples of the numerical control machine tool [9].
- 2) Combination of image and design elements: The main purpose of this stage is to discuss the relationship between the adjective vocabularies and design elements, and present this relationship in the manner of quantization. Its contents include a survey on the degree of images of Kansei and analysis of the relationship between design elements and image.
- 3) Construction of the Kansei Engineering system: This stage is mainly to integrate the construction results of the previous two stages, and this set of systems can be used as the main consulting contents between designer and enterprise.

2.2 Statistical method

The statistical methods used in the Kansei engineering are described, as follows:

- 1) Cluster Analysis: this is a kind of general logic program and an objective method, which can objectively collect the similarities in the same cluster according to the similarities and differences, and then, quantify them through structural features [12].
- 2) Multi-dimensional Scaling: called the MDS method; mainly researches people's feelings; so far, this research method has become the most commonly used technique in the development and evaluation methods of various kinds of new products in the design field, and is mainly applied into people's imagination or cognition of things, in order to judge the subjects' preference and conduct ranking or rating, analyze products' evaluation, and construct a preference cognition space diagram [19].

Figure 9: Method Semantic Differential

- 3) Semantic Differential Scheme: called the SD method; used to confirm subjects' attitudes towards each item through a series of polar multipoint rating scales, as shown in Figure 9 [2, 11].
- 4) Orthogonal Array Method: it is expected that there will be thousands of samples in this research, and it is certain that the questionnaire cannot be conducted at that time, thus, this method is used to reduce sample size by cooperating with SPSS software, and subjects can be tested smoothly.
- 5) Multiple Regression Analysis: this is a commonly used analysis method in statistics, and its purpose is to find the function relation between predictor variable (x) and dependent variable (y); Multiple Regression Analysis is the extension of regression analysis, and it is mainly used to add multiple predictor variables into a regression equation, in order to increase the predictive ability of regression and reduce the residual value; the linear relation between predictor variable and dependent variable is assumed, thus, it can be indicated by the Multiple Linear Regression Model.

Suppose that there are p predictor variables: x_1, x_2, x_p and L, and the relationship between these variables and dependent variable y_i is:

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + L + \beta_p x_{ip} + \varepsilon_i$$

where, $\beta_0, \beta_1, L, \beta_p$ is the coefficient; ε_i is the independent random residual variable ($Cov(\varepsilon_i, \varepsilon_j) = 0$), and it conforms to the expectancy value of 0, and variance σ^2 is the normal distribution. Suppose that there are n groups of sample sizes, and their model is shown, as follows:

$$\begin{aligned} y_1 &= \beta_0 + \beta_1 x_{11} + \beta_2 x_{12} + L + \beta_p x_{1p} + \varepsilon_1 \\ y_2 &= \beta_0 + \beta_1 x_{21} + \beta_2 x_{22} + L + \beta_p x_{2p} + \varepsilon_2 \\ &\vdots \\ y_n &= \beta_0 + \beta_1 x_{n1} + \beta_2 x_{n2} + L + \beta_p x_{np} + \varepsilon_n \end{aligned}$$

As the expectancy value of ε_1 is 0, the expectancy value of y_i is $E(y_i) = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + L + \beta_p x_{ip}$, and each y_i conforms to the expectancy value of $E(y_i)$ and normal distribution of variance of σ^2 . It can also be indicated through the following matrix and vector:

$$Y = x\beta + \varepsilon$$

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ M \\ y_n \end{bmatrix}, X = \begin{bmatrix} 1 & x_{11} & x_{12} & L & x_{1p} \\ 1 & x_{21} & x_{22} & L & x_{2p} \\ M & M & M & & M \\ 1 & x_{n1} & x_{n2} & L & x_{np} \end{bmatrix}, \beta = \begin{bmatrix} \beta_1 \\ \beta_2 \\ M \\ \beta_n \end{bmatrix}, \varepsilon = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ M \\ \varepsilon_n \end{bmatrix}$$

Multiple Regression Analysis was used in this research to establish the mapping relation formula between modeling and vocabulary, and then, to calculate the predicted value for comparison with other results analyzed by artificial intelligence. Therefore, Multiple Regression Analysis includes multiple independent variables, which often affect the overall relationship due to the special order of the causal relationship; therefore, when Multiple Regression Analysis is applied for prediction, there are two different analysis methods, simultaneous multiple and stepwise multiple regression, which incorporate independent variables into the combination of the regression equation [15].

2.3 Grey Theory

Under the situation of an unclear system model and incomplete information, the Grey Theory mainly conducts relational analysis and model construction of the system in order to discuss and understand the actual situation of the system through the methods of prediction and decision making. Grey Theory includes 4 fields in application: 1) Grey Generation; 2) Grey Relational Analysis; 3) Grey Model; 4) Grey Prediction. The grey system theory is used in this research to rank the weight values of effects of the modeling component elements on Kansei vocabularies, and further select the samples at the front end of ranking for transformation and design.

2.4 Product design method-image board

After the Kansei factors of the modeling aesthetics of the numerical control machine tool are obtained through various analysis methods, creative thinking is used to “guide” and “enlighten” designers’ creative elements, and transform their concepts into the modeling aesthetics of a numerical control machine tool, including the following design methods:

- 1) Design method of image representation: its purpose is to simulate users’ desire for products, and transform concept images into product modeling designs through representation association and a short description of the concept; its basic procedure is: association → transformation → materialization [6, 8].
- 2) Transformation process from picture image to product: its connotation is discussed and interpreted according to the pictures, in order to abstract relevant symbolic image elements to express picture creation quintessence, and then, transform it into a modeled design of the product;

its basic procedure is: picture collection → picture selection → element selection → modeling development [6].

- 3) Design method of image transformation: first, it is mainly used to define the function scope of a product, technology principle, usage principle, operation function, usage situation, and social significance, which is combined with the concept of association, as narrated by the representational method, in order to produce image vocabularies intended for product design, and then, several differential image vocabularies are converged into an image advertising board in order to intensify the designers’ product modeling association and simulation methods in modeling development; its basic procedure is: establishment of prototype → image association → reinforcement of association → transformation [4, 6, 8].

3. ANALYSIS RESULTS AND CASES OF PRACTICAL DESIGN

3.1 Selection of subjects

All samples adopted in this research had a design background, and subjects were mainly divided into two groups of students and practitioners; in terms of students, students trained by the integrated industrial designs of CNC machine tools and practical research courses of the Industrial Development Bureau, Ministry of Economic Affairs, were selected. Practitioners were mostly designers with more than 5 years of practical experience in industrial design, for a total of 30 young persons aged from 20-35 years old. As the automatic control machine tool belongs to important machinery production equipment, and it is irrelevant to daily life and consumption, the economic factors of subjects are not considered.

3.2 Sample collection and cluster analysis

First, the CNC machine tool samples of a well-known brand were widely collected; in order to make the research contents meet market requirements, the adopted samples were mostly products launched between 2010 and 2016, for a total of nearly 200 samples; the samples that were repeated or could not be recognized were deleted; finally, 50 samples were adopted. Samples were made into picture cards, classification testing was conducted among subjects, and subjects put the samples with similar style or image into the same groups according to their subjective identification of the images, for a total of 5-7 classification groups. The above test results were summarized into a 50×30 matrix, which was transformed into a 50×50 dissimilarity matrix of Euclid straight-line distance through a SPSS program; the data was input into SPSS

for MDS analysis, analysis from two dimensions to six dimensions was conducted in order, and the dimension analysis results are as shown in Table 2.

According to the stress coefficient table of Kruskal, stress coefficient must be lower than 0.05, thus, the data have significance; during the determination of dimension quantity, its explanatory ability, ease of use, and practicality should be considered; after evaluation, the group quantity with the best performance was selected as the grouping boundary line. The contents of the five dimensions conform to a good definition; therefore, five-dimensional data were used to carry out hierarchical clustering analysis, which adopted the Ward's method, and the grouping results are, as shown in Figure 10.

Table 2: Stress coefficient value from two dimensions to six dimensions

Dimensions	Stress	RSQ
2	0.17395	0.86965
3	0.08620	0.95784
4	0.05860	0.97681
5	0.03569	0.99031
6	0.01804	0.99730

Figure 10: Grouping results

Classification of category 1					
No.	Distance	No.	Distance	No.	Distance
1	0.552	19	0.541	40	0.711
7	0.659	20	0.517	41	0.592
11	0.750	23	1.010	42	0.861
12	1.116	25	0.689	43	0.541
13	0.465	26	0.511	44	0.430
14	0.719	27	0.531	45	0.511
15	0.598	31	0.437	46	0.596
16	0.887	36	0.572	47	0.437
17	0.897	37	0.695	48	0.437
18	0.516	38	0.871	49	0.821

Figure 11: Representative sample in the first cluster

Based on the grouping results in Figure 10, the group quantity with the best performance was selected as the grouping boundary line, and the K average cluster method was used for analysis; with the use of K average cluster method, the distance between each sample and the center of gravity of this group was obtained; where the smallest center of gravity of distance can be considered as the representative sample of this cluster; the representative samples of each subgroup obtained by this research are as shown in Figure 12; in addition to the representative sample in the first cluster shown in Figure 11, quantitative analysis is conducted from the second cluster to the fifth cluster, in order to identify the representative samples for follow-up research.

3.4 Selection of Kansei vocabulary

According to the company's catalog information of the numerical control machine tool, as well as the wide scope of information collected in the industrial report, in order to reduce the loading on subjects' modeling during the process of the experiment, similar adjectives were deleted through subjective evaluation, and then, 60 Kansei adjective vocabularies related to modeling aesthetics were sorted for testing; subjects selected 15-20 adjective vocabularies according to their own perception of the modeling of the numerical control machine tool they had seen, and the statistical results are, as shown in Table 3. Finally, 15 Kansei vocabularies with the highest votes were selected, and used as basis for follow-up SD scale analysis according to the relative vocabularies, as shown in Table 4.

Table 3: Kansei vocabularies of modeling aesthetics of numerical control machine tool

Vocabulary	Number of votes	Vocabulary	Number of votes
1 Modern	40	31 Sharp	6
2 Novel	38	32 Modular	20
3 Professional	41	33 Luxurious	25
4 Concise	42	34 Enormous	26
5 High-end	27	35 Mobile	30
6 Fashionable	49	36 Upright	19
7 Precise	27	37 Simple	3
8 Cutting-edge	10	38 Outstanding	27
9 Appealing	36	39 Durable	17
10 Stable	35	40 Characteristic	12
11 Grand	25	41 Mature	10
12 Innovative	27	42 Abiding	0
13 Safe	38	43 Inflexible	0
14 Advanced	25	44 Conservative	0
15 technology	26	45 Rare	2
16 Trendy	27	46 Convenient	13
17 Streamlined	22	47 Intelligent	40
18 Expensive	40	48 high-speed	25
19 Unique	20	49 Graceful	22
20 Generous	5	50 Energy-saving	18
21 Futuristic	36	51 Excellent	26
22 Rare	5	52 Refined	28
23 Complex	9	53 Reliable	12
24 Sleek	15	54 Critical	5
25 Traditional	0	55 Geometric	7
26 Rigid	3	56 Digital	9
27 Deep	9	57 Human-oriented	10
28 Graceful	10	58 Practical	38
29 Clean	32	59 Ideal	3
30 Thick	5	60 Soft	0

Table 4: Relative adjective vocabularies and SD rating scale example

Relative adjective vocabularies		
1 Modern-Traditional	6 Appealing-Ugly	11 Clean-Dirty
2 Novel-Obsolete	7 Stable-Fluctuating	12 Mobile-Sluggish
3 Professional-Novice	8 Safe-Risky	13 Intelligent-Mediocre
4 Concise-Complex	9 Expensive-Cheap	14 Refined-Coarse
5 Fashionable-Outdated	10 Futuristic-Past	15 Practical-Theoretical
SD rating scale- a case study of Modern-Traditional		
Modern ☐ ☐ ☐ ☐ ☐ ☐ ☐ Traditional		

The 15 groups of coded adjective vocabularies and 5 pictures of the numerical control machine tools, as selected by the screened sample pictures, were prepared into a questionnaire with a 7-order scale; after the test was conducted by the subjects, the data of the Kansei evaluation matrix were analyzed, as shown in Table 5.

Factor analysis was carried out against the matrix contents in Table 5, and its main purpose is to show the original data dimension with fewer dimensions. With a factor eigenvalue greater than 1 as the principle, the potential features of these image adjectives were determined, rendering the representative significance of each

Table 5: Rating table of Kansei evaluation matrix

Code	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5
1	1.31	4.10	6.13	6.57	3.33
2	1.21	4.23	1.89	5.71	3.17
3	1.89	3.47	2.76	4.29	3.51
4	2.34	2.79	4.71	4.13	4.57
5	6.23	1.17	1	4.37	5.13
6	2.17	6.57	6.79	5.21	4.79
7	3.50	2.01	2.37	2.17	2.93
8	3.01	1.23	3.53	5.63	5.41
9	2.79	2.01	5.41	3.17	4.71
10	1.59	1.79	3.01	3.29	4.23
11	2.47	2.51	4.01	2.97	5.10
12	3.43	3.27	3.79	3.13	4.29
13	1.89	3.47	2.49	4.71	2.79
14	3.19	3.50	5.89	3.01	3.28
15	3.37	3.67	3.23	3.47	4.27

Table 6: Factor analysis of Kansei adjectives

Factor	Image vocabulary	Factor value	Eigenvalue	Contribution degree	Accumulated contribution degree
Novel	Modern-Traditional	0.813	6.828	45.520	45.520
	Novel-Obsolete	0.916			
	Refined-Coarse	0.734			
	Concise-Complex	0.749			
	Fashionable-Outdated	0.901			
	Appealing-Ugly	0.910			
	Expensive-Cheap	0.563			
Clean	Intelligent-Mediocre	0.756	3.364	22.424	67.944
	Professional-Novice	0.889			
	Futuristic-Past	0.612			
Safe	Clean-Dirty	0.913	2.575	17.166	85.110
	Mobile-Sluggish	0.863			
	Stable-Fluctuating	0.794			
	Safe-Risky	0.923			
	Practical-Theoretical	0.794			

factor more obvious and easier to explain, thus, it can be found that the Kansei vocabularies of the numerical control machine tool have three common factors, aesthetics, modeling, and design, and analysis results are, as shown in Table 6.

It can be seen from Table 6 that, a larger factor loading means a higher correlation between this Kansei vocabulary and the factor, thus, the above analysis shows that the key factor affecting the design aesthetics of the numerical control machine tool lies in whether the presented aesthetics is novel; the key factor affecting modeling lies in whether the modeling itself is clean and crisp; and the key factor affecting design lies in the safety presented by the numerical control machine tool.

3.5 Product decomposition

There were 5 representative samples selected through cluster analysis; after cross checking and observation, the design elements of the CNC machine tool were determined, and there are 7 design elements: 1) modeling

of metal plate; 2) feeding door of workpiece; 3) access door; 4) operation box; 5) window; 6) heat emission hole; 7) color, and each element has several kinds of types, which are coded according their types, as shown in Table 7.

If the 7 design elements are extended according to modeling, there will be 21600 ($6 \times 3 \times 4 \times 5 \times 5 \times 4 \times 3$) different samples; however, it is certain that the subjects cannot bear such large data. Therefore, with the application of the orthogonal array and quantitative methods, this research used SPSS statistical software for the reduction of sample size, in order to obtain 81 samples. However, as this was still too large a sample size, the selection of observation value in the option of SPSS was adopted, and 19 samples were selected for follow-up research after calculation with the quantitative method.

The quantitative method was used to calculate the sample size required by this research, and a small sampling was conducted to confirm the ratio between standard deviation and average value. A sample test was conducted among subjects in this research, and the models not suitable for overall match-up were deleted; finally, 8 modeling samples were selected for follow-up analysis and model deconstruction distribution in the analysis results, as shown in Table 8.

Table 7: Table of design elements

modeling of metal plate (A)
feeding door of workpiece (B)
access door (C)
operation box (D)
window (E)
heat emission hole (F)
color (G)

Table 8: Model deconstruction distribution

	A	B	C	D	E	F	G
S1	7	4	3	4	1	1	3
S2	3	9	3	6	6	4	1
S3	2	4	8	8	4	3	4
S4	4	8	9	7	2	1	4
S5	4	4	5	2	3	1	1
S6	8	8	1	7	6	2	2
S7	9	1	7	4	5	3	4
S8	2	7	4	7	1	5	4

Table 9: Rating table of final Kansei evaluation matrix

	Novel-Obsolete	Clean-Dirty	Safe-Risky
S1	2.13	5.79	2.34
S2	3.71	4.17	4.15
S3	5.67	1.56	4.57
S4	3.49	5.77	3.18
S5	3.23	4.71	3.27
S6	3.79	4.15	3.21
S7	5.67	1.77	5.15
S8	2.56	6.55	1.47

Then, the final Kansei evaluation matrix was carried out; every subject observed the sample picture of the numerical control machine tool and selected a suitable rating options according their own perception; the 3 groups of Kansei vocabularies and the feeling values of the 8 kinds of modeling samples of the numerical control machine tool were arranged in a quantized matrix, as shown in Table 9.

3.6 Establishment of relationship between design elements and Kansei vocabulary

The statistical method used in this stage is Multiple Regression Analysis, which can gain the influence degree of different **design elements** on Kansei vocabulary to obtain the basis for follow-up practical design. This research took the **design elements** of 8 product samples as the independent variables and 3 groups of Kansei vocabularies as dependent variables. From the data of Kansei evaluation matrix, we obtain the following regression results, as shown in Table 10.

On the other hand, we may obtain the weighting of design elements on each Kansei vocabulary from the data of Kansei evaluation matrix. A part of the results is shown in Figures 12-14.

Table 10: Results of Multiple Regression Analysis

	y_1 Novel-Obsolete	y_2 Clean-Dirty	y_3 Safe-Risky
Project	Coefficient	Coefficient	Coefficient
x_1	0.029	0.435	-0.235
x_2	0.598	-0.436	0.239
x_3	-0.268	0.115	-0.193
x_4	-0.133	0.501	-0.324
x_5	-0.143	-0.058	-0.027
x_6	0.197	0.413	-0.162
x_7	-1.639	1.821	-1.864
Constant term	6.692	-2.103	9.802
	$R = 0.868$ $R^2 = 0.753$ Significance: 0.027	$R = 0.907$ $R^2 = 0.822$ Significance: 0.047	$R = 0.802$ $R^2 = 0.643$ Significance: 0.035

Figure 12: y_1 The influence weight of each parameter

Figure 13: y_2 The influence weight of each parameter

Figure 14: y_3 The influence weight of each parameter

In Figures 12 to 14, the X axis refers to the parameter of each modeling, and Y axis refers to the weight value of each vocabulary parameter; through such visualized expression, it can be clearly understood how to cooperate with creative thinking to carry out integration designs for each component in the following practical design.

4. APPLICATION OF CREATIVE THINKING INTO PRACTICAL DESIGN AND SURVEY ON DESIGN SATISFACTION

The beginning and end of creative thinking are understood according to the literature review and design steps, in terms of product positioning, characteristic vocabulary and association, integration of design elements and design sketch, and image conversion of digital design according to the logic reasoning of the design procedures, and related implementation contents are described, as follows:

4.1 Product positioning and image representation

In this stage, the main design element is to provide definite product positioning to the numerical control machine tool, and the designer in this part can directly judge the basic characteristics of the numerical control machine tool through observation. At this stage, the researchers and 3 industry designers discussed the design development of the numerical control machine tool, and formulated the following 4 items through creative thinking and association: overall modeling, product function, interface system, and basic construction. In addition to quoting the former analysis contents of the items, multiple items are subdivided according to various considerations, in order to provide definite positioning for the design of numerical control machine tool, as shown in Table 11.

Based on the contents in Table 11, and in terms of the vocabulary of “Novel” in the Kansei vocabulary and pattern characteristics, the modeling of the metal plate has the higher effect weight. Therefore, during the creative development of the modeling of the metal plate, the design of the novelty item will be considered, where the numerous conditions obtained in the above product positioning are combined for design development.

Table 11: Application of creative thinking and association into the design and product positioning of the numerical control machine tool

Product positioning	Positioning item	Positioning content
	Overall modeling	Extremely simplified modeling, sense of novelty, briefness and comparability of color
	Product function	Workpiece vehicle, milling, slicing, cutting, and other multiple combined processing methods
	Interface system	Push-button operation, touch panel operation, and other multiple modular interface systems
	Basic component	Metal plate, feeding door of workpiece, access door, operation box, window, heat emission hole, color

4.2 Characteristic vocabulary and characteristic association

In this stage, the characteristic vocabulary is established, the concrete images that can express product modeling are determined by the designers, and some keys are extracted from the free imagination stage by cooperating with the direction of product positioning: “basic pattern-sense of novelty”, “color-briefness, comparability”, etc. Many image objects are associated through the characteristic vocabulary, which is sorted and shown in Table 12. The association of the image object is integrated to establish a picture advertising board, as shown in Figure 15.

4.3 Integration of design element and design sketch

In this stage, after observing the picture advertising board of characteristic association in Figure 14, the new design idea, principles, and systematic framework, as provided by association, are transformed into design elements, and the integrated design elements are shown in Table 13.

Table 12: Process of characteristic vocabulary and characteristic association

	Basic pattern	Color
Characteristic vocabulary	Sense of novelty	Briefness and comparability
Characteristic association	The vision of the numerical control machine tool should avoid tradition and present the first impression of a future perspective.	Softness or hardness, depth, thickness, decorative effect, shadow

Figure 15: Picture advertising board of characteristic association

Table 13: Integrating design elements from the picture (focus on the representation picture)

	Picture advertising board	Integrated design element
Future conceptual modeling		The extremely simplified geometrical line matched with broken line effect is the modeling development
Shadow vision		Change of shadow, application of direct ray of light, reflection, indirect lighting, light guiding, and other effects

The integrated design elements in Table 13 mainly focus on the representative picture, and in the remaining picture advertising board, with the same integration method, relevant design elements are integrated. In-depth design and development are conducted according to all the design elements, while a design sketch is created according to the Kansei vocabulary and modeling component elements, as shown in Figure 16.

4.4 Image conversion of digital design

Product revisions are made in the drawn sketch in order to revise all the modeling component elements of the items, and confirm whether the adjustment of details and color configurations are suitable, in order to transform them into digital design pictures, as shown in Figure 17.

According to the 3 factors for the CNC machine tool, as analyzed by the Kansei vocabulary, the design concepts are described, as follows:

- 1) Aesthetics: the extremely simplified geometrical line is matched with the effect of the broken line; meanwhile, the color comparison is considered for modeling development, and the principle of avoiding tradition and presenting a novel sense of aesthetics is adhered to during the process of design.
- 2) Modeling: the modeling is presented in a clean plane and face, and the briefness and comparison of color and the changing effects of shadows are applied to present the highlights of the modeling design.
- 3) Design: the numerical control machine tool belongs to equipment with high risk during operation; regarding the operator’s safe operation of equipment, the cladding modeling design of the metal plate, marginal adaptation of the metal plate, sound insulation, waterproofing, etc., are all main safety considerations.

Figure 16: Design sketch

Figure 17: Digital design picture of numerical control machine tool

Table 14: Score of customer satisfaction

	Normalized Mean
S1	0.44
S2	0.51
S3	0.60
S4	0.57
S5	0.33
S6	0.47
S7	0.52
S8	0.46
Integrated design of creativity	0.77

Table 15: Integrating design elements from the picture (focus on the representation picture)

Sample	Integrated design of creativity	S3
Average mean	0.77	0.60
Upgrade rate	28.3%	

4.5 Survey on design satisfaction

A questionnaire survey of customer satisfaction was performed to verify the proposed methodology. The survey results (product image: novel) are shown in Tables 14 and 15.

The satisfaction evaluation results of subjects regarding the modeling in Table 15 show that, the method of conducting the modeling aesthetic design of a numerical control machine tool through analysis of the product's Kansei Engineering and cooperating with creative thinking, the results are accepted by most subjects, and such analysis and design method can inspire the development of the designer's creativity in the course of design, in order to improve the reference degree of modeling aesthetics of a numerical control machine tool.

5. CONCLUSION

With the use of our proposed integrative methodology including Kansei Engineering and creative image board, we may design a new CNC machine tool meeting customers' requirement. This study extends the ability of traditional Kansei engineering scheme in which it usually deals with known customer's feeling about a product. However, customers always prefer new things. How to acquire the past customers' information about a product (Kansei engineering), use this information as a design basis, and then accordingly implement the creative idea to generate a new product form (creative image board), is the main contribution of this study. The proposed integrative methodology can be easily applied to other kinds of products, not limited to CNC machines.

REFERENCES

1. Huang-Pin Lin; The study of information product's kansei trait by consumer's opinion - personal computer as an example, Graduate Program of Design and Arts College, Da-Yeh University, 1997.
2. Meng-Wei Lin; Integration on Kansei Engineering Product Design through Association Thinking, Master's thesis, Department of Creative Product Design, Ling Tung University, 2012.
3. Hsiao-Hui Fan; A Research on Design Method for transforming image into Idea of Styling, Master's thesis, Department of Industrial Design, National Cheng Kung University, 2004.
4. Yueh-Chang Kao; A Study on Product Image and Its Representation Design - with Radio Design as a Case Study, Journal of Design, 1996.
5. Tsu-Wei Chang; The Creative Development of Integrative Method in Concept Design, Master's thesis, Graduate Program of Design and Art College, Da-Yeh University, 2006.
6. Shun-Te Chang; Research into the Method of Improving Creativity, Journal of Business Administration, pp.71-95-130, 1999.
7. Hung-Yi Chen and Jui-Tse Tu; Research & Development Team, Creative Design Center, Taiwan, Research into Connection and Application of Green Design Trend and Material Kansei Engineering, International Symposium on Sustainable Products and Industrial Management, 2011.
8. Tai-Sheng Huang and Hsueh-Ling Hong; Application of Product Semiotic on Product Design, Chaoyang Journal of Design, 2, 2001.
9. Ching-Hsuan Huang; Rhetoric, San Min Book Co., Ltd., Taipei City, 2000.
10. Ting-Chun Tung and Chuan-Fang Li; A Study of the Relation between Visual Communication Design and Kansei Engineering, Journal of Design Research, 3, pp.214-220, 2003.
11. Wei-Wen Lai; Applying Kansei Engineering on Configuration Design of Injection Molding Machines, Master's thesis, Graduate Program of Industrial Design, 2009.
12. Hongbin Yuan and Abby Parrill; Cluster analysis and three-dimensional QSAR studies of HIV-1 integrase inhibitors, Journal of Molecular Graphics and Modelling, 23(4), pp.317-328, 2005.
13. Baek, S., Hwang, M., Chung, H., and Kim, P.; Kansei factor space classified by information for Kansei image modeling. Applied Mathematics and Computation. 205, pp.874-882, 2008.

14. Chen, C. C., Chung, M. C.; Integrating the Kano model into a robust design approach to enhance customer satisfaction with product design. *International Journal of Production Economics*, 114, pp.667-681, 2008.
15. Cross, N.; *Engineering design methods: Strategies for Product Design*. John Wiley & Sons, Chichester, 2000.
16. Elias, C., John, C.; Creative system design methodologies: the case of complex technical systems. *Technovation*, 25, pp.831-840, 2005.
17. Huang, M. S., Tsai, H. C., and Huang, T. H.; Applying Kansei engineering to industrial machinery trade show booth design. *International Journal of Industrial Ergonomics*, 41, pp.72-78, 2011.
18. Ishihara, S., Ishihara, K., Nagamachi, M., and Matsubara, Y.; An automatic builder for a Kansei Engineering expert system using self-organizing neural networks. *International Journal of Industrial Ergonomics*, 15(1), pp.13-24, 1995.
19. Kruskal, J. B.; Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. *Psychometrika*, 29, pp.1-27, 1964.
20. Yang, C. C.; Constructing a hybrid Kansei engineering system based on multiple affective responses: Application to product form design. *Computers & Industrial Engineering*, 60, pp.760-768, 2011.

Hong-Yi CHEN (Non-member)

He is a Ph.D at Graduate School of Design Doctoral Program, National Yunlin University of Science and Technology in Taiwan. He is a Lecturer of Design Education at Computer-Aided Industrial Design Department, Overseas Chinese University, Changhua Taiwan, after having contributed for 7 years of Design Research. He is engaged in the design theory, the research method, and statistical of questionnaire. His research interests are Kansei Engineering, Design Education, Industrial Design, Cultural and Creative Industry.

Jui-Che TU (Non-member)

He is a professor of Graduate School of Design in National Yunlin University of Science and Technology in Taiwan. He received his MS and Ph.D. degrees in industrial Education from the University of Tennessee of the United States in 1987 and 1991, respectively. His specialties are industrial product design, green (environmental) design, lifestyle design, cultural creative design and design education development. His main concentration of research focuses on methods of industrial product design and development, such as theoretical techniques and methodological procedures of product green (sustainable) design and consumer lifestyle and needs. As a result of his studies, he hopes to provide a guideline and application for R&D, planning and marketing of products in industries

Kun-Chieh WANG (Non-member)

Prof. Kun-Chieh Wang is Associate Dean of School of Design and Information, and also the Director of Department of Computer-Aided Industrial Design of Overseas Chinese University. He has dedicated his life to design and development of Numerical Control Machine Tool, and made a great contribution to mechanical design and industrial design, in both academic and industrial fields. In recent years, he has been committed to applying Kansei Engineering to the field of mechanical design, in order to making important changes in mechanical design industry, and pioneering a new aspect of it.