
Cognitive Analysis of Product Form Elements

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Abstract

Perception is the most basic form of cognition thinking activity. Consumers' perception image to the product form is based on human's visual perception characteristics, which can be summarized as the overall organization, the constant memory, the simple regulating and the identifiable discrimination according to the Gestalt principle. Firstly, the study analyzes the characteristics of consumers' perception image to the product form. Secondly, the evaluation model that is used to simulate consumers' image perceived behavior is build using gray correlation analysis and fuzzy neural network. Finally, the practice example of car side profile design is taken, and the results show that the method is helpful to product form image intelligent design.

Keywords: product design, gray correlation analysis, fuzzy neural network, form cognition

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1. Introduction

Product form is the language and intermediary of the design ideas and use function. The product design is not only to realize the use function, but also to convey the meaning and symbol of the spirit and culture. So, the product form is the integrated result of the product objective factors such as the function, structure, material and technology interact with the aesthetic and value judgment of designers and consumers [1].

In the consume market, especially to the daily products, the aesthetic function of product has become one of the most important factors that influence consumers deeply [2]. The complexity of modern technology and the diffusion of technology make it impossible that the technical level of a product overtops others. In other words, the products which participate in the competition in mature market have the same technical level and application function. In this case, the personalization and fashion become the decisive factor when consumers purchase products [3], and the product appearance is the most direct way to reflect personality [4]. Therefore, the excellent products must not only have good function, interface, operation mode and technical characteristics, but also need to have wonderful appearance and even emotional factors in order to meet the psychological needs of consumers. Perception is the most basic form of cognition thinking activity. Consumers' perception image to the product form is based on human's visual perception characteristics, which can be summarized as the overall organization, the constant memory, the simple regulating and the identifiable discrimination according to the Gestalt principle [5]. Product form image design is based on human visual perception, and it develops design program with the form factors as object and the irrational Kansei cognition information as starting point [6]. Its main theory is Kansei Engineering [7], and one of the difficult and hot research of Kansei Engineering is how to enhance the Kansei Engineering system with artificial intelligence [8-10]. Based on thinking science [11], the research on Consumers' image perception thinking [12, 13] is an effective way to solve the problem. The related researches focus on the transfer technology of Consumers' image perception [14, 15], and are lacking in considering Consumers' Kansei cognition characteristics. The prediction accuracy of the model is low.

The study analyzes the characteristics of Consumers' perception image to the product form firstly. Secondly, the evaluation model that is used to simulate Consumers' image

perceived behavior is built using gray relational analysis and fuzzy neural network. Finally, a practical example of car side profile design is taken.

2. The Characteristics of Cognition

The human cognition processes is fuzzy and has learning ability. And the research methods used in this study focus on these two characteristics.

Knowledge is human's subjective image to the objective world and the human. The fuzzy cognition is formed from the thinking of the objective world, it reflects the judgment characteristics of the human's cognition level to the objective world. From the view of information processing, the knowledge acquisition depends not only on the reasoning, but also on the cognition thinking with fuzzy characteristics. The cognition thinking is hierarchical. And there are recessive of varying degrees and fuzziness of different levels in cognition thinking. The image thinking process is not linear, it's three-dimensional and wide, and has a strong imagination. Some abstract imagination only can be sensed by them, and is difficult to express to others. There is a certain ambiguity. In intuitive thinking and creative thinking, it's full of human's fuzzy image thinking of intuition, inspiration, epiphany, and also full of sense thinking of "can only be felt, not explained" [16].

Learning is a behavior to gain experience or a relatively long-lasting adaptive change of behavior potential of human and animal in the life course. Animal and human are inseparable from learning, and learning makes them exist, develop and maintain a balance with environment. In other words, learning is the means to adapt to environment for them. Learning activities, even the simplest learning, is not the activity of a single cell, but a comprehensive activity of a large number of neurons. These neurons constitute a complex network.

3. Product Design Parameters Identification Technology

In this study, the product parameters are identified with gray relational grade, the important attributes that affect the system development trends are defined according to gray relational grade. The designer can analyze the mutual influence between various determining factors and measure the contribution of the factors to behavior according to the microscopic or macroscopic geometric proximity of factor sequences. In the field of product form image design, it helps designers understand the correlation between the design elements and image, and sort out the form features that meet the Kansei demand to define the key design elements.

Product form elements and categories are classified and numbered according to morphological analysis. Kansei image vocabularies are collected, and the representative vocabularies are selected according to cluster analysis. Based on the semantic differential method, a 5-level SD questionnaire for each pair of Kansei vocabularies and n samples is designed to survey the consumers' Kansei evaluation to samples.

$$x_0(k) = (x_0(1), x_0(2), \dots, x_0(n)) \quad (1)$$

The decision matrix D is defined.

$$D = [x_i(k)]_{ik} \quad (2)$$

And the elements of decision matrix is $x_i(k)$.

$$x_i(k) = (x_i(1), x_i(2), \dots, x_i(n))$$

Therefore, the decision matrix can be expressed as:

$$D = \begin{bmatrix} x_0(1) & x_0(2) & \dots & x_0(n) \\ x_1(1) & x_1(2) & \dots & x_1(n) \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ x_m(1) & x_m(2) & \dots & x_m(n) \end{bmatrix}$$

Where, $i=0, 1, 2, \dots, m, k=1, 2, \dots, n, i, k \in N$.

$x_0(n)$ is reference sequence, the other m groups sequence are comparative sequences, and every sequence contain n factors. In this study, the Kansei evaluation $x_0(k)$ of n samples is reference sequence, the other m groups comparative sequence represent the various design elements and categories. The sequences are normalized, and a normalized matrix S is defined as:

$$S = [x_i^*(k)]. \quad (3)$$

Where,

$$x_i^*(k) = \frac{x_i(k)}{\sum_{k=1}^n x_i(k)}$$

According to distance method, the m sequences are processed to form an $m \times n$ normalized matrix $x_i^*(k)$. Every elements of each column in normalized matrix minus $x_0(k)$, and the absolute values constitute a difference sequence matrix Δ .

$$\Delta = \begin{bmatrix} |x_1^*(1) - x_0(1)| & |x_1^*(2) - x_0(2)| & \dots & |x_1^*(n) - x_0(n)| \\ |x_2^*(1) - x_0(1)| & |x_2^*(2) - x_0(2)| & \dots & |x_2^*(n) - x_0(n)| \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ |x_m^*(1) - x_0(1)| & |x_m^*(2) - x_0(2)| & \dots & |x_m^*(n) - x_0(n)| \end{bmatrix} \quad (4)$$

Gray relational coefficient is defined as:

$$r(x_0(k), x_i(k)) = \frac{\Delta_{\min} + \xi \Delta_{\max}}{\Delta_{0i}(k) + \xi \Delta_{\max}} \quad (5)$$

Where,

$$\begin{aligned} \Delta_{0i}(k) &= |x_0^*(k) - x_i^*(k)|, \\ \Delta_{\min} &= \min_i \min_k |x_0^*(k) - x_i^*(k)|, \\ \Delta_{\max} &= \max_i \max_k |x_0^*(k) - x_i^*(k)|. \end{aligned}$$

ξ is identification coefficient, it's used to adjust the contrast between the original object and the object to be measured, and $\xi \in [0,1]$. If the identification coefficient is smaller, then the correlation is stronger. Gray relational coefficient is the correlation between reference sequence and compare sequence level, and $0 \leq r(x_0(k), x_i(k)) \leq 1$.

Gray relational grade is defined as the average of the gray correlation coefficient.

$$r(x_0, x_i) = \frac{1}{n} \sum_{k=1}^n r(x_0(k), x_i(k)) \quad (6)$$

According to sorting gray relational grade, it's able to assess the influence of the design elements to Kansei image, and then identify the individual parameters and platform parameters.

4. Kansei Image Prediction Model

Fuzzy neural network combines the advantages of fuzzy system and neural network, and abandons the disadvantages of them. It has the uncertain information processing capability of the fuzzy system and self-learning ability of the neural network. There is a very broad application prospects in the field of control forecast. Fuzzy neural network can be used to verify the correctness of the individual parameters and platform parameters based on the gray relational analysis. The human brain has the ability to learn and fuzzy cognition features in the perceptual process, and the characteristics of neural networks and fuzzy system correspond with them. Neural network has a strong ability to adapt and learn, but it can not deal with fuzzy information. Fuzzy rules, membership function and other design parameters rely heavily on experience, so fuzzy system lacks the ability of self-learning and adaptation. Fuzzy neural network achieves the complementarity of neural network and fuzzy system; it applies neural networks to construct fuzzy system. According to the input and output samples, the system automatically adjust the design parameters in order to simulate the analysis better and forecasting process of human brain [17].

The establishment of the neural network input layer is determined by the study object, it comprises the input layer nodes and the input data. In this study, the input layer nodes is the total number of coordinate of the key point when sample contour is quantized, and the input data is the coordinates of the respective key point. Fuzzification means to transform the clear signal into a fuzzy set described by the membership grade. The process is used to test the exact value of variables and transform them into appropriate words and phrases according to its ambiguity and membership function. In this study, the neural network output the fuzzy Kansei evaluation in the form of ambiguity function membership grade.

In this study, triangular fuzzy number is used to represent the Kansei evaluation [18, 19]. The triangular fuzzy number is a specific case of fuzzy sets. Three elements (t_1, t_2, t_3) express a triangular fuzzy number and represent a probability distribution as shown in Figure 1.

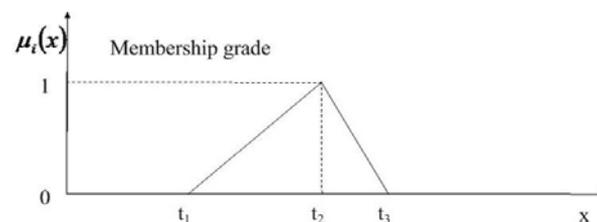


Figure 1. Triangular Fuzzy Number and Membership Grade

Membership grade is expressed by:

$$\mu_i(x) = \begin{cases} 0, & x < t_1 \\ \frac{x-t_1}{t_2-t_1}, & t_1 \leq x \leq t_2 \\ \frac{x-t_3}{t_2-t_3}, & t_2 \leq x \leq t_3 \\ 0, & x > t_3 \end{cases} \quad (7)$$

It is generally believed that the increase of middle layers can reduce network errors and improve accuracy, but it also increases the network complexity, training time and the

tendency of over-fitting. Horink has proved that if the input layer and output layer apply linear transfer function and the middle layer applies Sigmoid transfer function, the MLP network with a middle layer can approach any rational function with arbitrary precision [20]. So, a 3-layer neural network is adopted in this study. The middle layer nodes are very important. It influences the performance of network for it is the direct cause of over-fitting. The basic principle of the middle layer nodes is that when the accuracy requirements is meet, the structure of network should be as compact as possible. Typically, the middle layer nodes are a half of the sum of the input layer and output layer nodes. Defuzzification means to transform the output fuzzy values into clear values. Membership grade $\mu_{out}(x)$ can be defined as a polyline connect to the output nodes in turn. In order to get the value of Kansei image, it is necessary to obtain the center of gravity of polyline. It is defined as:

$$x_{CG} = \frac{\int_0^1 x \mu_{out}(x) dx}{\int_0^1 \mu_{out}(x) dx} \quad (8)$$

A fuzzy neural network is created, and its parameters such as weight and error are adjusted in the training process. It is shown in Figure 2.

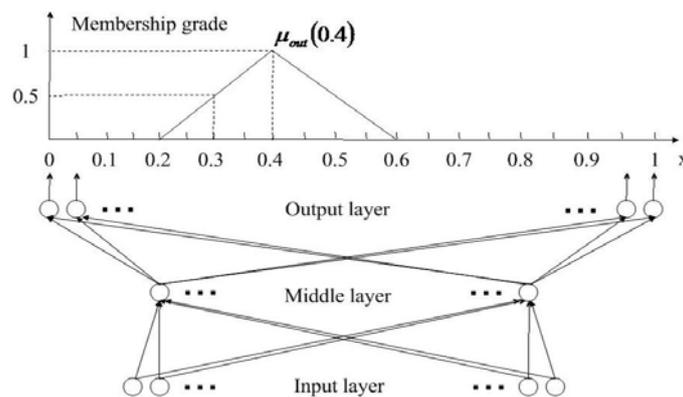


Figure 2. Fuzzy Neural Network

In this study, the level of Kansei evaluation is divided into five classes, and they are defined as 5 points on the axis. The normalized numbers are 0, 0.25, 0.5, 0.75 and 1. According to the semantic differential method, if the value of Kansei evaluation ranges from -0.125 to 0.125, it belongs to the class represented by the point. For example, the number 0.25 represents the second class, as shown in Figure 3. If the Kansei evaluation is in the region of 0.125 to 0.375, it is considered that the Kansei evaluation belongs to the second class. Therefore, when the error absolute value between the forecast value of neural network and the evaluation of subjects is less than 0.125, the predicted result is acceptable.

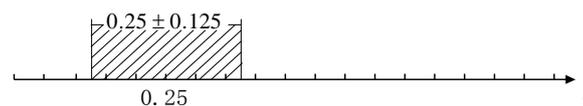


Figure 3. Reasonable Error Range

5. Case Study

The researchers collect a large number of lateral view images of car, and choose 50 images as the experimental samples as shown in Table 1.

Table 1. The Experimental Samples

1	2	3	4	5
				
6	7	8	9	10
				
11	12	13	14	15
				
16	17	18	19	20
				
21	22	23	24	25
				
26	27	28	29	30
				
31	32	33	34	35
				
36	37	38	39	40
				
41	42	43	44	45
				
46	47	48	49	50
				

Then, all the samples are quantified as shown in Figure 4. The side contour is defined by 27 key points, which directly change the side contour. At the same time, the key points are the basis of design elements and categories of side contour.

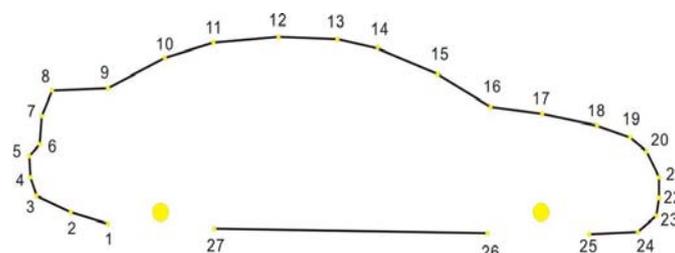


Figure 4. Side Contour of Car

According to the key points, side contour of car is divided into following elements: the form of head end (A1), the thickness of head end (A2), the lower section outline of head end (A3), the hood angle (B1), the hood radians (B2), the form of car canopy (C), the form of trunk lid (D), the form of trail (E1), the thickness of trail (E2), the lower section outline of trail (E3); three proportional relationship: the length of hood/the length of car canopy (F), the length of

trunk lid/the length of car canopy (G), the length of car/the height of car (H). The design elements are described and classified based on qualitative methods as shown in Table 2.

Table 2. Design Elements and Categories

	1	2	3	4	5	6
A1	Circular	Semicircular	Bald	Square	Stepwise	Sharp
A2	53~61	61~69	69~77	77~85	85~93	
A3	Long and parallel	Long and fastigate	Short and parallel	Short and fastigate		
B1	0.11~0.14	0.14~0.17	0.17~0.20	0.20~0.23	0.23~0.26	
B2	Small	Medium	Large			
C	Broken line	Stream line	Oval			
D	Long and parallel	Long and fastigate	Short and parallel	Short and fastigate	Without	Backward tilt
E1	Circular	Stepwise	Square	Circular-square	Sharp	
E2	79~87	87~95	95~103	103~111	111~120	
E3	Long and parallel	Long and fastigate	Short and parallel	Short and fastigate		
F	0.32~0.37	0.37~0.42	0.42~0.47	0.47~0.53	0.53~0.58	
G	Without	0.14~0.17	0.17~0.20	0.20~0.23	0.23~0.26	
H	0.24~0.255	0.255~0.27	0.27~0.285	0.285~0.30	0.30~0.315	

Finally, the design elements of 50 quantized samples are classified to ensure that each element is described according to design elements and categories in Table 2. In this study, a survey questionnaire is designed to survey Consumers' Kansei evaluation to various cars. Firstly, the researchers collect a lot of Kansei vocabularies that describe the car contour. And then the subjects pick out six Kansei vocabularies (Dynamic, stylish, elegant, flow lines, stationary and personalized). Finally, a 5-level questionnaire is designed according to 6 Kansei vocabularies and 50 samples. The researchers calculate and obtain the Kansei evaluation average of each sample. To Kansei vocabulary "dynamic", for example, the design elements and Kansei evaluation average of each sample are shown in Table 3.

Table 3. The Design Elements and Kansei Evaluation Average

Sample	Design elements and categories													Kansei Dynamic
	A1	A2	A3	B1	B2	C	D	E1	E2	E3	F	G	H	
Sample 1	3	3	1	3	1	1	1	2	4	1	4	3	2	2.94
Sample 2	1	5	1	2	1	3	1	2	4	2	4	3	3	3.34
Sample 3	3	3	4	3	3	2	5	1	4	1	5	1	2	3.28
Sample 4	1	4	3	1	1	2	6	3	3	4	5	3	1	4.10
...						
Sample50	1	3	2	5	2	2	2	1	3	2	2	2	2	4.00

Table 4. The Sort of Design Elements

Element	$\xi=0.2$	Sort	$\xi=0.3$	Sort	$\xi=0.4$	Sort
A1	0.482566	13	0.572746	13	0.634812	13
A2	0.610798	7	0.688212	7	0.73852	7
A3	0.559572	12	0.642855	12	0.698612	12
B1	0.616235	6	0.691085	5	0.740225	4
B2	0.645459	2	0.721222	2	0.769094	2
C	0.577061	9	0.658858	9	0.713201	10
D	0.617059	4	0.690557	6	0.739078	6
E1	0.616775	5	0.693481	3	0.743235	3
E2	0.562895	11	0.645324	11	0.700201	11
E3	0.570193	10	0.656708	10	0.713449	9
F	0.680175	1	0.749672	1	0.793542	1
G	0.617779	3	0.691425	4	0.739754	5
H	0.591595	8	0.66495	8	0.714329	8

Kansei evaluation average of samples and category number are used to construct the original decision matrix to calculate the gray relational grade. If the gray relational grade of

elements are too similar, it will be difficult for designers to distinguish parameters. The identification coefficient ξ should be adjusted so as to strengthen or weaken the contrast of gray relational grade. When the identification coefficients are 0.2, 0.3, 0.4, the calculation results are shown in Table 4.

Table 5. The Coordinates of Key Points of Test Samples

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 50
x1	270	264	272	260	265
y1	190	184	178	180	188
x2	220	222	240	232	227
y2	194	190	180	184	195
x3	192	186	204	200	188
y3	208	204	188	192	205
x4	187	181	196	188	183
y4	224	220	204	224	222
x5	186	180	194	186	180
y5	244	242	222	250	237
x6	196	194	198	190	179
y6	260	256	230	258	251
x7	200	196	200	191	192
y7	282	276	258	270	283
x8	210	198	223	192	190
y8	298	298	284	284	296
x9	262	260	278	254	243
y9	300	304	306	284	305
x10	320	324	336	314	302
y10	328	328	322	304	326
x11	372	398	390	374	348
y11	344	346	328	320	339
x12	424	440	434	430	408
y12	347	350	330	324	345
x13	480	490	476	472	478
y13	345	348	330	324	345
x14	527	534	520	516	530
y14	338	340	325	320	338
x15	580	588	566	556	585
y15	312	318	304	302	316
x16	620	632	608	592	638
y16	288	292	280	286	289
x17	680	694	672	660	702
y17	281	284	277	282	281
x18	728	750	733	730	757
y18	274	276	266	273	267
x19	777	784	760	756	782
y19	261	266	252	266	253
x20	791	800	786	778	792
y20	244	253	235	254	236
x21	800	808	786	786	792
y21	230	228	214	226	208
x22	800	809	782	785	790
y22	213	211	200	212	193
x23	800	807	784	784	793
y23	194	190	186	193	189
x24	780	778	761	760	774
y24	186	178	179	182	182
x25	736	738	732	736	735
y25	184	174	176	182	178

The sort results shows that the contribution of design elements B1, B2, F, G to Kansei image "dynamic" is great, and the elements A1, A3, E2 have a small contribution to Kansei image "dynamic". So, the elements B1, B2, F, G are defined as individual parameters, and the elements A1, A3, E2 are defined as platform parameters. The parameter identification results are conducive to the positioning, design and improvement of design elements. 50 samples are divided into two groups. The 7th, 16th, 26th, 30th and 47th samples are randomly selected as test samples to verify the training results of fuzzy neural network. The remaining 45 samples are used to train the network. The input layer nodes of network are equal to the total number of coordinate of key points on the sample outline. There are 27 points on the sample outline, but the 26th and 27th points affect the form of chassis only, so the first 25 points are chosen as key points, and 50 coordinates are defined. Therefore, the total number of input layer nodes is 50, and the input data is the coordinates of key points of 45 samples as shown in Table 5.

The Kansei evaluation is divided into five levels, and the corresponding relationship between Kansei evaluation hierarchy and triangular fuzzy number is shown in Table 6.

Table 6. Corresponding Relationship

Kansei evaluation	Triangular fuzzy number
1	0, 0, 0.25
2	0, 0.25, 0.5
3	0.25, 0.5, 0.75
4	0.5, 0.75, 1
5	0.75, 1, 1

The output of network is the three elements (t_1, t_2, t_3) of triangular fuzzy number, which is normalized. According to the characteristics of the triangular fuzzy number, 21 nodes divide the axis 0 to 1 into 20 segments, and these nodes are the output layer nodes as shown in Figure 5.

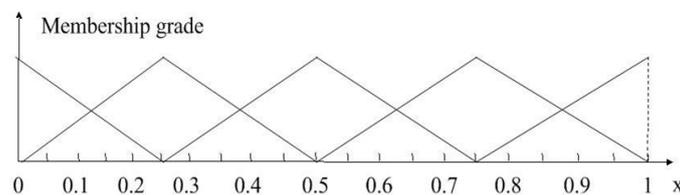


Figure 5. The Output Layer Nodes

There is a middle layer in the network. There are 50 input nodes and 21 output nodes in network, so the number of middle layer nodes is 36. The researchers set the parameters of network such as refresh frequency, learning rate, momentum constant, the number of training and convergence error. After repeated training, the network eventually converges to an acceptable error. To compare with the actual data, the output data is decoded with defuzzification method to get the intuitional analysis results. The analysis results of the Kansei image "dynamic" is shown in Table 7.

Table 7. THE ANALYSIS RESULTS of the Kansei Image "dynamic"

Actual data	0.4754	0.3115	0.5574	0.7377	0.1230
Prediction date	0.5010	0.2024	0.5539	0.7388	0.1555
Error	0.0256	-0.1091	-0.0035	0.0011	0.0325

The results show that the error of five test samples is in a reasonable error range, and it is proved that the prediction method based on fuzzy neural network is feasible.

In order to predict the Kansei evaluation of new sample without the platform parameters, the researchers exclude the design elements A1 and A3 according to the gray relational grade sort of 6 Kansei image. In actual operation, the node that affects the individual parameter and platform parameter should be retained. For example, the node x21 affects platform parameter A1 and individual parameter H, so it is retained in the forecast process. According to the key points on the outline, the nodes that affect platform parameters A1 and A3 are shown in Table 8.

Table 8. Platform Parameters and Associated Nodes

Platform parameters	Associated nodes
A1	x22, x23, y21, y22, y23
A3	x25, y25

These nodes are removed from the input layer of network. The researchers adjust the middle layer, and train the network again. And the verification results are shown in Table 9.

Table 9. The Verification Results

Actual data	0.4754	0.3115	0.5574	0.7377	0.1230
Prediction date	0.2916	0.2262	0.5899	0.6717	0.1761
Error	-0.1838	-0.0853	0.0325	-0.0660	0.0531

To the Kansei image "dynamic", the results show that four errors in the five sample forecast results are in reasonable range, the forecast accuracy rate is 80%. For other Kansei images, the prediction accuracy can reach 80%. It is evident that the results of platform parameter identification are correct.

6. Conclusion

In this study, the researchers calculate and sort the gray relational grade between design elements and Kansei image with gray relational analysis, analyze the Kansei evaluation and forecast the Kansei evaluation of the products without platform parameters using fuzzy neural network. The results show that the gray relational analysis method can be used to identify the platform parameters and individual parameters of product, and fuzzy neural network is applicable to predict Kansei evaluation.

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