Study on the Perception of Car Appearance Based on Fuzzy Inference

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Abstract. This paper proposes fuzzy logic to forecast perception values of the combination of different design elements. Firstly it extracts customers' semantic information with semantic difference method; applies GRA analysis to find the key form elements for each perception, and builds the fuzzy membership between the form element and perception. Then it generates a set of fuzzy rules with the most influential form elements based on the 10 representative car samples and calculates the perception values on different combinations of the form design elements by defuzzification.

Keywords: sensory characteristics, gray correlation, fuzzy logic, fuzzy rules, fuzzy solution.

1 Introduction

With the social development and scientific & technological progress, the concepts of "humanity", "personalized" and "user-oriented design" have rooted deeply in people's mind, and also become a pursuit goal in modern product design. In order to achieve the pursuit goal of user-oriented innovation in design, it is necessary to build a bridge between the product designers and the consumers, which can understand and predict consumers' behavior and their evaluation to the product image better. Many scholars from overseas have donated themselves in the perception research of the product appearance. Hsu et al. [10] pointed out that there might be a big scale on the perception of a same product between the designer and consumer, thus the designer should consider the needs and the favors of the consumers while designing. J. Park and S.H. Han [7] from Korea applied the fuzzy rule methods to establish a relationship model between the consumers' satisfaction and the design elements in office chair design, and then made a contrast between this method and traditional ones such as linear regression and quantification theories. S. Hsiao and H-C. Tsai [12] from Taiwan established the relationship between the semantic words and the input parameter based on fuzzy neural network and genetic algorithm.

This paper takes car appearance as the research object, makes use of fuzzy logic method to forecast perception values on different combinations of the form design elements. It is organized as follows. In Section 2 the literature review is summarized. In Section 3, a model reflecting the design variables and image preference is proposed by fuzzy logic which is then illustrated with an example. In Section 4 conclusion is given.

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2 Literature Review

The globalization of competition in industry and the diversification of customers' demands as well as rapid technological developments continue to spur design-based innovations at a frenetic pace. Holbrook and Hirschman mentioned that customers' perception has played a decisive role in purchasing mature products such as car and electric goods. Perception is the nature of the information age, which leads us logically entered into a perceptual era. H-C Chang et al. [4] explored five expression modes used by consumers in conveying desire for product form, the results of which provide a foundation for the future development of enhanced investigation techniques aimed at understanding consumers' latent desires for product form. Raphaelle [9] studied the relationship between the perceptual variables and the design elements by regression analysis. S. Baek et al. [13] from Korea constructed a perceptual factor space where the perceptual vocabulary can reflect the visual information. H-B Yan et al. [3] from Japan, proposed the perceptual evaluation technology based on the multi-attribute fuzzy target-oriented decision analysis, and defined three types of fuzzy targets to represent the consumers' preferences and extended to quantify how well a product meets consumers' preferences. L-Y Zhai et al. [8] from Singapore applied rough set in evaluating human's perception of a product. H-Y Chen and Y-M. Chang [5] from Taiwan took advantage of NDSA method to extract the key design elements which influence consumer's preference most. Carmen Llinares and Alvaro F [1] from Spanish informed the differential semantic method as an analysis tool on analyzing the emotional impression in the field of Kansei Engineering.

3 Steps to Establish a Fuzzy Prediction Model and Exemplification

3.1 A Selection of Design Variables

As car is a product in large size and complex feature, this paper studies it from the most direct observation angle, namely the side exterior angle. Therefore, the key side design elements which influence consumer's perception effectively are selected after literature research and advice combination of three industrial engineers. The result is shown in table 1.

3.2 A Selection of Feeling Feature Semantics

Consumers use a range of simple adjectives when expressing their perceptions of a particular product. These adjectives provide an explicit representation of the consumers' abstract emotional response to a product's form, and can therefore furnish designers with valuable clues regarding the consumers' product image expectations and the success (or otherwise) of the generated product form in meeting its design objectives. In the current study, 29 emotional words (in Chinese) pertaining to car were collected from web sites, magazines, catalogues and so forth. These adjectives were sieved by a questionnaire survey and data analysis in accordance with the criteria outlined below such that just 15 representative emotional words remained, namely angular-streamlined, static-dynamic, hulking-ingenious, ordinary-original, popular-personalized, economical-expensive, unsafe-safe, complex-concise, flimsy-burly, regular-honorable, exquisite-generous, straitness-spacious, clutter- harmonious, classical-fashionable, dislike-favorable..

- Criterion 1: Retain the adjectives only if they are chosen by more than 50% consumers in describing the perception of the car image in a questionnaire survey.
- Criterion 2: Retain the adjectives only if the related coefficient between the customers' favor and the perceptual adjectives more than 0.3 based on the data analysis.

Table 1. Car Side Exterior Design Variables

Car side design variables		Type 1	Type 2	Type 3
X1	Headstock type	Long and lordosis(L,X_{11})	Moderate length(ML,X_{12})	Extremely short(S,X_{13})
X2	Car tail type	Obvious kyphosis(VL,X_{21})	A little kyphosis(L,X_{22})	
X3	Radian of front window	Smooth transition (P,X_{31})	Micro-edges transition (PA,X_{32})	Edges transition(A,X_{33})
X4	Radian of rear widower	Smooth transition (P,X_{41})	Micro-edges transition (PA,X_{42})	Edges transition(A,X_{43})
X5	Roofline type	straight(L,X_{51})	A little arch camber(C,X_{52})	Vault (VC,X_{53})
X6	Body side molding type	Obvious (D,X_{61})	Not obvious (ID,X_{62})	
X7	prominence of Wheel casing	Obvious (D,X_{71})	Not obvious (ID,X_{72})	
X8	Wheel spoke type	sparse linear leaf (T,X_{81})	Dense linear leaf (VT,X_{82})	floriated (F,X_{83})

3.3 A Collection of Questionnaire and Data Analysis

The representative car pictures used in questionnaire have been got through the magazine, Internet research, site visits, and advertising vocabulary. In order to include most necessary information, we collected 47 car side pictures. Then the side pictures are classified by 20 experienced car designers. Later we construct similarity matrix between any two side pictures, and then transfer them into the "distance matrix". Through the clustering analysis based on the principle of minimum clustering center distance, we filtrate 10 side pictures whose center distances are minimum. According to the questionnaire survey, we got the mean score, scoring range and standard deviation of each picture to the representative emotional words, which is shown in table 2.

Table 2. Numerical data source for the 10 representative side car samples

Car No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	Angular-streamlined				ingenious	…	favorable
									mean	min	max	St-deviation	mean	…	mean
C1	1	1	2	2	2	1	1	1	3.98	1	6	1.50	4.02	…	3.65
C2	2	2	1	1	3	2	2	1	5.89	2	7	1.00	5.28	…	5.07
C3	2	1	2	2	3	1	1	2	4.74	1	7	1.70	4.43	…	3.93
C4	1	1	3	1	1	2	2	2	3.76	1	7	2.10	3.20	…	3.83
C5	1	2	2	1	2	1	2	3	3.57	1	7	1.60	4.65	…	3.57
C6	1	2	2	3	1	2	1	1	2.89	1	7	1.70	4.26	…	3.11
C7	1	1	1	3	1	1	1	1	3.30	1	7	1.60	3.65	…	3.43
C8	1	1	3	2	1	1	1	3	4.67	1	7	1.60	4.30	…	4.24
C9	1	1	3	3	2	1	2	2	3.93	1	7	1.70	3.87	…	3.89
C10	3	2	1	1	3	1	1	3	5.63	1	7	1.40	4.52	…	4.83

3.4 Establish a Fuzzy Prediction Model Reflecting the Design Variables and Feeling Feature

3.4.1 The Determination of Input Variables and Output Variables

It is important to determine the input variables, output variables and fuzzy rules in the construction of a fuzzy prediction model. This paper takes car side pictures as research objects, takes the corresponding design variables as input variables, and takes the emotional words as the output variables, so as to predict the score of each emotional word based on the establishment of fuzzy rules. During the determination of the fuzzy rule of input and output, it is not simply taking all the side design variables as input ones, but choose the key design variables which have a closely relationship with emotional words through GRA analysis.

The construction of GRA relationship can be defied by the example of side design variable namely "angular-streamlined" in table2. The following table3 shows the relational results $r\left(X_0, X_i\right) \in \left(0,1\right)$ of each design variable $\left(X_i, i = 1, 2, \cdots, 8\right)$ to emotional words "angular-streamlined" $\left(X_0\right)$. If there is $r\left(X_0, X_i\right) > r\left(X_0, X_j\right)$, it means that the design variable X_i has a bigger influence on emotional words X_0 "angular-streamlined" compared with the design variable X_j ,the bigger the score of $r\left(X_0, X_i\right)$ is, the bigger the influence is. For example, the design variable X_5 "roofline type" has a correlation value of 0.76, which means that the roofline type influenced the emotional word "angular-streamlined" X_0 most. Then X_2 "car tail", X_8 "wheel spoke", X_7 "prominence of Wheel casing" and X_6 "Body side molding" also have influences in the emotional word of "angular-streamlined". According to this result, it may remind the designers to focus on these design variables when they want to improve the consumer's feeling feature of "angular-streamlined". The other design variables such as X_1 "headstock", X_3 "front window" and X_4 "Radian of rear window" which has little influence on the emotional word can be ignored.

Table 3. Correlation value between side design variables and the emotional semantic "angular-streamlined"

Car No.	Side design variable								Angular-streamlined
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	
1	0.49	0.66	0.97	0.97	0.97	0.66	0.66	0.49	1.00
2	0.50	1.00	0.33	0.33	1.00	1.00	1.00	0.33	1.00
3	0.71	0.52	0.71	0.71	0.63	0.52	0.52	0.71	1.00
4	0.52	0.71	0.48	0.52	0.52	0.48	0.48	0.92	1.00
5	0.55	0.46	0.85	0.55	0.85	0.76	0.46	0.46	1.00
6	0.68	0.40	0.66	0.40	0.68	0.40	0.97	0.68	1.00
7	0.60	0.85	0.60	0.43	0.60	0.85	0.85	0.60	1.00
8	0.42	0.53	0.62	0.73	0.42	0.53	0.53	0.62	1.00
9	0.50	0.67	0.50	0.50	1.00	0.67	0.50	1.00	1.00
10	0.88	0.88	0.35	0.35	0.88	0.42	0.42	0.88	1.00
Correlation value	0.59	0.67	0.59	0.55	0.76	0.63	0.65	0.67	1.00

This paper selects the key design variables which has a correlation value more than 0.6 with the feeling feature semantics. And this is regarded as the fuzzy rule in the following research. The following table4 delivers the results of key design variables of each semantic word.

Table 4. Key design variables of each semantic word

Semantic word	Key side design variable					Semantic word	Key side design variable			
Angular-streamlined	X2	X5	X6	X7	X8	Exquisite-generous	X1	X2	X4	
Hulking-ingenious	X2	X5	X8			Ordinary-original	X2	X3	X5	X8
Unsafe-safe	X1	X2				Straitness-spacious	X1	X2	X3	X5
Economical-expensive	X1	X2	X3	X4	X8	Clutter-harmonious	X3	X4	X5	
Complex-concise	X2	X5	X6	X8		Classical-fashionable	X2	X3	X8	
Static-dynamic	X2	X3	X5			Popular-personalized	X2	X3	X8	
Flimsy-burly	X1	X3	X4	X7		Dislike-favorable	X2	X5	X7	X8
Vulgar-honorable	X3	X6	X7							

3.4.2 The Obfuscation of Design Variables and Feeling Feature Semantics. There are many forms of fuzzy number, among which the triangular fuzzy number, trapezoidal fuzzy number and Gaussian fuzzy model are the most common ones. They appear as useful means of quantifying the uncertainty in decision making due to their intuitive appeal and computationally efficient representation.

This paper constructs a series of subordinate function based on the combination of triangular fuzzy number and trapezoidal fuzzy number. The triangular fuzzy subordinate function $\mu_A(x)$ is constructed by the triangular fuzzy number (a,b,c), and $a,b,c\,(a \le b \le c)$ is three specific numbers, which is shown in formula 1.

$$\mu_A(x)=\begin{cases} 0, & x<a, \\ \dfrac{x-a}{b-a}, & a \le x \le b, \\ \dfrac{x-c}{b-c}, & b \le x \le c, \\ 0, & x>c. \end{cases} \tag{1}$$

The triangular fuzzy number (a,b,c) can express the approximate value of the fuzzy semantics, among which b represents the most likely value, a the max value, and c the min value. The definition of each variable subordinate function is determined by the number of the design types, which is shown in table 1. Taking X1 "Headstock type" as an example, it has three types, namely Long and lordosis type(L,X_{11}), Moderate length type(ML,X_{12}), and Extremely short type(S,X_{13}), the matching degree of each picture with each type can be described in number ranging from 1 to 3. for example, the number 1.5 can be seen as a half combination of type X11 "long and lordosis" and the other half type X12"moderate length" As there may be more than number 4 in value during the subsequent valuation after X13, the trapezoidal fuzzy number (2,3,4,4)is then used to describe this kind relationship. The triangular fuzzy numbers for the side design variables are finally constructed and the results are shown in table5.

Table 5. Triangular fuzzy numbers for the side design variables

Side design variables	Design types and corresponding triangular fuzzy numbers		
Headstock typeX1	Long and lordosis(L,X_{11}) (1,1,2)	Moderate length(ML,X_{12}) (1,2,3)	Extremely short(S,X_{13}) (2,3,4,4)
Car tail type X2	Obvious kyphosis (VL,X_{21}) (1,1,2)	A little kyphosis (L,X_{22}) (1,2,3,3)	
Radian of front window X3	Smooth transition (P,X_{31}) (1,1,2)	Micro-edges transition (PA,X_{32}) (1,2,3)	Edges transition(A,X_{33}) (2,3,3)
Radian of rear widower X4	Smooth transition (P,X_{41}) (1,1,2)	Micro-edges transition (PA,X_{42}) (1,2,3)	Edges transition(A,X_{43}) (2,3,3)
Roofline type X5	straight(L,X_{51}) (1,1,2)	A little arch camber(C,X_{52}) (1,2,3)	Vault (VC,X_{53}) (2,3,4,4)
Body side molding type X6	Obvious (D,X_{61}) (1,1,2)	Not obvious (ID,X_{62}) (1,2,3,3)	
prominence of Wheel casing X7	Obvious (D,X_{71}) (1,1,2)	Not obvious (ID,X_{72}) (1,2,3,3)	
Wheel spoke type X8	sparse linear leaf (T,X_{81}) (1,1,2)	Dense linear leaf (VT,X_{82}) (1,2,3)	floriated (F,X_{83}) (2,3,3)

According to the data from table5, the input variables can be constructed by the combination of triangle subordinate function and trapezoidal subordinate function together, namely each style of the design variable owns its own subordinate function. There are a total of 8 groups of subordinate functions. Based on this, the fuzzy rules of the fuzzy prediction model can be established.

During the process of constructing the subordinate function of the output variables (namely the feeling feature semantic words), the emotional word can be described by 7 levels with a reference of the questionnaire. Taking the “angular-streamlined” for example, its value can be extremely angular, very angular, angular, medium, streamlined, very streamline, and extremely streamlined. The corresponding triangular fuzzy number are shown in table 6. Following the same way, all the subordinate functions of the other feeling semantics can be constructed.

Table 6. Triangular fuzzy numbers for the semantic variables "angular-streamlined"

Semantics and its triangular fuzzy numbers						
Extremely angular (1,1,2)	Very angular (1,2,3)	angular (2,3,4)	medium (3,4,5)	streamlined (4,5,6)	Very streamlined (5,6,7)	Extremely streamlined (6,7,7)

3.4.3 The Establishment of the Fuzzy Rules

In order to establish the fuzzy rules more objectively, this paper makes the mean of the 7-level feeling semantics scores of 10 pictures as the output value. Taking car picture C1 as an example, the mean of the score to semantic word “angular-streamlined” is 3.98 (seen in table2). The computation process of the semantic subordinate degrees of “medium” and “angular” are shown as follows.

Semantic subordinate degree of “medium” is $0.98 = \frac{(1-0)\times(3.98-3)}{(4-3)+0}$

Semantic subordinate degree of “angular” is $0.02 = \frac{(1-0)\times(4-3.98)}{(4-3)+0}$

Table 7. Fuzzy rules for determining the "angular-streamlined" value of car side design elements

rule	IF					THEN	
	X2	X5	X6	X7	X8	Angular-streamlined	Supporting degree(Dos)
1	VL	C	D	D	T	medium	0.98
2	VL	C	D	D	T	angular	0.02
3	L	VC	ID	ID	T	Very streamlined	0.89
4	L	VC	ID	ID	T	streamlined	0.11
5	VL	VC	D	D	VT	streamlined	0.74
6	VL	VC	D	D	VT	medium	0.26
7	VL	L	ID	ID	VT	medium	0.76
8	VL	L	ID	ID	VT	angular	0.24
9	L	C	D	ID	F	medium	0.57
10	L	C	D	ID	F	angular	0.43
11	L	L	ID	D	T	angular	0.89
12	L	L	ID	D	T	Very angular	0.11
13	VL	L	D	D	T	angular	0.7
14	VL	L	D	D	T	medium	0.3
15	VL	L	D	D	F	streamlined	0.67
16	VL	L	D	D	F	medium	0.33
17	VL	C	D	ID	VT	medium	0.93
18	VL	C	D	ID	VT	angular	0.07
19	L	VC	D	D	F	Very streamlined	0.63
20	L	VC	D	D	F	streamlined	0.37

The semantic subordinate degree represents its supporting degree to the corresponding fuzzy rules (Dos), the value is between 0 and 1. What’s more, the supporting degree (Dos) also shows the weights of the fuzzy rules, which can be seen in the last column of the table 7.

In order to reflect all the design variables of the car form, this paper adopts the multiple fuzzy rules, which is shown as follows. IF X_1 is A_1 AND X_2 is $A_2 \cdots$ AND X_n is A_n, THEN Z^* is B. From this formula, $A_1, A_2, \cdots A_n$ and B are all fuzzy semantic items, which are determined by both the output variables $X_1, X_2, \cdots, X_n$ (the car design element which has a link with semantic word) and output semantic variables Z^* (semantic adjectives). The values are all expressed in triangular fuzzy number. According to the 10 side pictures, 20 (10*2=20) fuzzy rules are constructed. Each fuzzy rule can connect the car design elements with its corresponding semantic adjectives. Taking the “angular-streamlined” as an example, the fuzzy rule is established in table 7.

Based on the fuzzy subordinate function and the fuzzy prediction table, the fuzzy prediction model can be established with a help of fuzzy tools supplied by Matlab.

3.5 Exemplification

The fuzzy rules are all followed effectively during the process of the fuzzy prediction. The input variable determines the matching degree with its corresponding output variable. The result we get from fuzzy prediction is a fuzzy subordinate function or a fuzzy subset. While in fact, an actuator should be controlled to make sure that there should be only a certain amount of control on a certain time. An accurate value should be found to represent the fuzzy set which shows the distribution possibility of the fuzzy control from fuzzy output subordinate function. This process is called defuzzification. This paper adopts the Centriod method which is most popular nowadays to deal with the defuzzification. The computation is shown in formula 2 as follows

$$^{y}COM = \frac{\sum_i \left[\mu(y_i)\times y_i\right]}{\sum_i \mu(y_i)} \tag{2}$$

i stands for the semantic of output variable (such as "angular" or "streamlined"), y_i is the max of the semantic variable i ,(such as "angular" or "medium"), $\mu(y_i)$ is the output subordinate function value after aggregation. Based on the defuzzification method, the fuzzy prediction process can be solved using Matlab function evalfis( ).

In order to verify the fuzzy prediction model, this paper makes an additional random choice of five car side pictures with different combinations of the design variables, which is shown in fig.1. Taking the fuzzy rule on semantic "angular-streamline" for an example, the design variable type of each picture is regarded as input variable as shown from column 2 to 6 of table8, the theoretical computation score of semantic "angular-streamlined" can be regarded as output variables after the process of defuzzification which is shown on column7 of table8. Meanwhile, the questionnaire are distributed again printing the selected ten pictures, and the mean of statistical score (add 4 based on the original score) to the semantic "angular-streamlined" are collected as shown on column 8.

Fig. 1. Car-side Pictures Chosen for testing

Table 8. Input, output and statistical values of the testing Car-side Pictures

Side picture	Subordinate design variable types					Angular-streamed	
	X2	X5	X6	X7	X8	Theoretical value	Statistical value
No.1	1.5	1.5	1.5	1.5	1.5	3.836	4.163
No.2	1.2	3.3	1.8	1.4	1.7	5.352	5.034
No.3	2	1	2.5	1	1.5	2.891	3.172
No.4	2	2.5	1.5	2	2.7	4.135	4.318
No.5	2.4	1.3	2.8	1.7	1	2.902	3.084

In order to evaluate the fuzzy prediction model, this paper adopts two testing methods, namely the T-test method and standard deviation calculation method. After SPSS software computation, T-test result is 0.10, which is larger than 0.05. This result demonstrates that there is no obvious difference between each design variable, and therefore the model is reasonable. The formula of standard deviation computation is as follows

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - x_0\right)^2}{n}} \tag{3}$$

x_i stands for the semantic output value of the car i, and x_0 stands for the corresponding semantic statistical score. If there is no significant error in both output value and the statistical value, then the RMSE value should be 0. The standard deviation of fuzzy prediction model and score statistical value can be computed, with a result of error 0.2652, which proves a very good consistency between the output value of the fuzzy prediction model and the semantic score.

4 Conclusion

This paper establishes a fuzzy prediction model based on the fuzzy control system. First the triangular subordinate function is constructed based on the triangular obfuscation of 8 side design variables and 15 feeling feature semantic words. Then the key design variables which have a close relationship with the feeling feature semantics are found to establish the effective fuzzy rules after the GRA (grey relationship analysis). Last the defuzzification is completed by the fuzzy toolbox supplied in Matlab software. Taking the semantic words “angular-streamlined” for an example, the scores of each design variables can be collected, and once more, the scores of other feeling feature semantic words to the corresponding design variables can be acquired, too.

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