A Method of Car Styling Evaluation Based on Eye Tracking

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Abstract. In order to remedy the weakness of traditional subjective evaluation method and acquire the users' objective assessment on automotive form design, a method of Auto form evaluation based on eye tracking is proposed. First, the index system is structured on the basis of heatmap including striping the background, extracting color characters by HSV model and calculating the statistic of grey level histogram. Second, the evaluation on auto form is defined as binary classification, and the function model is built by Fisher discriminate. The reliability and practicality of this method was validated by taking a case. The result showed that overall accuracy of this method was high. So a feasible technical approach for the rapid evaluation of automotive styling is provided.

Keywords: Car styling · Evaluation methods · Eye tracking · Feature extraction · Discriminate function

1 Introduction

2013' Survey of China Association of Automobile Manufacturers showed that more than 75% China users considered the physical appearance as the primary determinant factor when they planed to purchase cars [1]. Whether a car is accepted by the market depends largely on whether the car's styling design can win the praise of consumers. Usually users' ultimate psychological aesthetic evaluation originates from the car appearance recognition through the access of product images. On top of this, in recent years, the studies of car styling design involve two main aspects: design methodology and design evaluation.

Researcher Yadav et al. proposed a fuzzy approach which has been adopted for calculation of the relative importance of different aesthetic attributes; this proposed method has been illustrated using customer survey data and four out of 12 aesthetic attributes were found to be attractive [2]. It is very important for the current automobile industry to establish matching rules between wheel hubs and car types Luo et al., For the purpose of providing guidelines for wheel hubs selection, therefore, a case study on 6 typical types of cars and 20 wheel hubs was presented, examined their shape design styles and accordingly proposed a methodology for evaluating the perceptual matching

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quality [3]. In order to examine how companies strategically employ design to create visual recognition of their brands' core values, researchers Karjalainen carried out an explorative in-depth case study concerning the strategic design efforts of Volvo, and it was found that the company fostered design philosophies that lay out which approach to design and which design features are expressive of the core brand values [4].

About car design evaluation, a fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) approach which was integrated triangular fuzzy number, linguistic variables and TOPSIS was proposed to generate the overall performance score for each alternative, and the alternative with the highest score was finally chosen Zhang et al. [5]. In industry, design selection and refinement decisions are frequently based on consumers' one-time aesthetic impressions of a proposed design, so researchers Coughlan et al. reports on a study in which the same group of people were asked to evaluate a design prototype on two separate occasions at a 3-month interval, and the results reveal that their perceptions of a design concept appear to change with repeated exposure [6].

In general, the deficiencies exist in the previous study of car styling evaluation as following: ① Car form elements are usually interrelated, and then it is difficult to define them independently. So, the simple evaluation accumulation of the car form elements does not provide a complete result because users' comprehensive cognitive processing is based on overall product image. ② The evaluation to product design is fundamentally a kind of subjective description and perceptual knowledge based on intrinsic and external performance of products, although the previous study shows that the product image can be quantified. So this evaluation is still some kind description to the ambiguity phenomenon with individual differences. And the objective criteria are still lacked.

This paper presents a car styling evaluation method based on eye tracking feature, including: ① The HSV model is used to extract the color features and compute the statistic value of gray histogram. ② The car styling evaluation is defined as a problem of dichotomous, hence the discriminate function is constructed. Accordingly, the overall evaluation of car appearance modeling is realized and the objectivity standard is established.

2 Research Framework

Research shows that 80%–90% external information of human is obtained by visual sense. Since the middle of the 20th century, with the application of camera technology, especially the development of high-precision eye tracker, the research to eye movement in related disciplines is greatly promoted [7]. According to the previous study, the human eye movement mainly includes three ways: ① Fixation; ② Saccade; ③ Follow. The main parameters of eye tracking include: ① number of fixation points; ② fixation time; ③ fixation frequency; ④ fixation time ratio; ⑤ scan path; ⑥ first fixation point. With static forward range reaching 180°, users can quickly scan the features while observing the car shape. At the same time, the information processing of "feature bundling" is performed in the human brain. Therefore, the cognitive process of information can be obtained by eye tracking experiment, and overall evaluation to a car styling can be done.

2.1 Index System Establishment Based on Heatmap

In order to be applied in practice expediently, a large number of eye tracking data needs to be processed in a reasonable visualization manner to intuitively express the spatial and temporal distribution characteristics of eye movement data. At present, the main processing ways include: scanning path method, heatmap method, Area of interest method, three-dimensional space method, Andrienko et al. [8]. For the evaluation of car styling, the key is to measure the attractiveness index of the car features to the visual sense and compare the intensity of the influence of every feature on the image cognition. Heatmap can be used to find the most attractive visual object to the user, easily compare the intensity of product features, and it has the advantage of supporting multi-user data display. Therefore, the indicator system will be built based on heatmap in this paper.

Step 1. Color Feature Extraction. In order to coincide with human eye characteristics, the heatmap RGB model need to be transferred into HSV color model. In this HSV model, H represents color, $H \in [0, 360]$; S represents saturation, $S \in [0, 1]$; V represents brightness, $V \in [0, 1]$. Since the value of saturation and brightness in heatmaps are set to fixed, the chromaticity value is extracted as the color feature. Furthermore, the mean value of chromaticity, K is used as an indicator, i.e.

$$K = \frac{1}{N}\sum_{m=0}^{N} K_m \tag{1}$$

In formula (1), N is the total number of pixels in the heatmaps, and K_m is the chromaticity value corresponding to the m_{th} pixel.

Step 2. Gray Scale Histogram Feature Extraction. In order to obtain the further information, in this paper the method of gray histogram feature extraction is adopted to process the heatmaps. The grayscale histogram is essentially a discrete function representing the gray level, i.e.

$$H(i) = \frac{n_i}{N}, i = 0, 1, \ldots \ldots L - 1 \tag{2}$$

In the formula (2), i represents the gray scale, L represents the number of gray levels (0 to 255), n_i represents the number of pixels which have the gray scale i in the heatmap, and N represents the total number of pixels of the heatmaps. Based on above, the index system is established by statistical feature as shown in Table 1:

Table 1. Statistical indicators based on gray histogram

Indicator name	Interpretation	Calculation formula
Mean Value of Gray Scale	The average gray level of the image	$\mu = \sum_{i=0}^{L-1} iH(i)$
Variance	The discrete distribution of image gray value	$\sigma^2 = \sum_{i=0}^{L-1} (i-\mu)^2 H(i)$
Skewness	The asymmetry degree of the image histogram distribution	$\mu_S = \frac{1}{\sigma^3}\sum_{i=0}^{L-1} (i-\mu)^3 H(i)$
Peak State	The state of the gray distribution of the image close to the mean	$\mu_K = \frac{1}{\sigma^4}\sum_{i=0}^{L-1} (i-\mu)^4 H(i) - 3$
Energy	The uniformity of the squared gray distribution	$\mu_N = \sum_{i=0}^{L-1} H(i)^2$
Entropy	The uniformity of histogram grayscale distribution	$\mu_E = -\sum_{i=0}^{L-1} H(i)\log_2[H(i)]$

2.2 Sample Classification for Car Styling

The evaluation of car styling can be regarded as a process of samples classification essentially. That is, car styling would be divided into several levels such as not bad, good, very good and so on by the indexes. In the actual application, Two-Classifications which mean Auto forms are divided into two categories of G1 and G2 is implemented easily. For example, Auto form is divided into "high degree of recognition" and "low degree of recognition". Further the two categories of Auto form will be compared in order to sum up the design method of vehicle recognition, and the new vehicle model of the identification will be forecasted. Thus, in this article the definition is as following:

Definition 1. Let the set of vehicle samples be $C = \{C_1, C_2, C_3 \ldots C_n\}$, and the index of the color feature and the gray scale histogram feature from the vehicle samples heatmap are regarded as characteristics. So the set of characteristics is $X = \{X_1, X_2, X_3, X_4, X_5, X_6, X_7\}$. In the set, X_1 is Mean Value of Gray Scale (μ); X_2 is Variance (σ^2); X_3 is Skewness (μ_S); X_4 is the Peak State (μ_K); X_5 is the Energy (μ_N); X_6 is Entropy (μ_E); X_7 is mean value of chromaticity (K). The values above form a 7-row, n-column matrix:

$$\begin{bmatrix} X_{11} & X_{21} & X_{31} & \ldots & X_{n1} \\ X_{12} & X_{22} & X_{32} & \ldots & X_{n2} \\ X_{13} & X_{23} & X_{33} & \ldots & X_{n3} \\ X_{14} & X_{24} & X_{34} & \ldots & X_{n4} \\ X_{15} & X_{25} & X_{35} & \ldots & X_{n5} \\ X_{16} & X_{26} & \ldots & \ldots & X_{n6} \\ X_{17} & \ldots & \ldots & \ldots & X_{n7} \end{bmatrix} \tag{3}$$

For a vehicle model $C_j \in C(1 \leq j \leq n)$, its characteristics set is $\{X_{j1}, X_{j2}, X_{j3}, X_{j4}, X_{j5}, X_{j6}, X_{j7}\}$. So the Eigen-values can be composed of a seven-dimensional eigenvector values:

$$X_j = (x_1, x_2, x_3, x_4, x_5, x_6, x_7)^{\mathrm{T}} \tag{4}$$

Definition 2. A linear discriminate function is established for vehicle models in the following form:

$$d(x) = w_1x_1 + w_2x_2 + w_3x_3 + \ldots + w_7x_7 + w_8 \tag{5}$$

In the formula (5), $d(x)$ represents the discriminate value; $x_1, x_2 \ldots x_7$ represents six Eigen-values based on the heatmaps; $w_1, w_2 \ldots w_7$ represents the discriminate coefficient and the w_8 is the constant value. For two classifications of vehicle models, the following decision rules are adopted:

$$\boldsymbol{d}(\boldsymbol{x}) = \begin{cases} <0, \text{ then } \boldsymbol{S} \text{ belong to } \boldsymbol{G}_1 \\ >0, \text{ then } \boldsymbol{S} \text{ belong to } \boldsymbol{G}_2 \\ =0, \text{ then } \boldsymbol{S} \text{ belong to } \boldsymbol{G}_1 \text{ or } \boldsymbol{G}_2 \end{cases} \tag{6}$$

2.3 Linear Function Model Based on Fisher Discriminate

Fisher discriminate is recognized as one of the most effective methods for feature extraction [9], especially for dichotomous analysis. Its basic idea is to reduce the dimension by projection method so as to minimize the difference between similar samples and to expand the differences between different sample types. The projection line of the optimal direction needs to be obtained through sample training. So the linear function is constructed based on Fisher's discriminate.

The overall method flow in this paper is shown in Fig. 1:

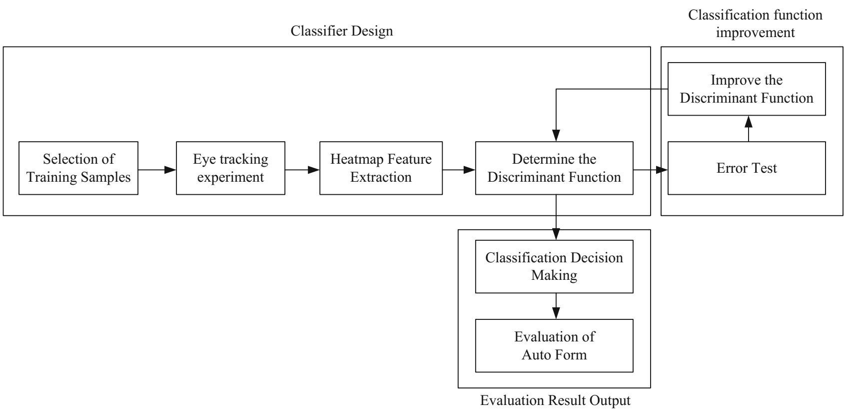

Fig. 1. The method of vehicle model evaluation based on eye tracking

3 Experimentation

In order to verify the above research framework, this paper verifies by experiment. The main experimental steps include: ① Training sample selection; ② Eye tracking tests and feature extraction of training samples; ③ Discriminate function model establishment.

3.1 Training Sample Selection

Car styling is classified as “high degree of preference (G1)” and “low degree of preference (G2)”. The front shape is the part which can convey the image and style information mostly. Total of 30 pictures of different brands of car were collected. And the pictures are processed as achromatic color, and the resolution was set to 600 dpi. A total of 17 participants have average more than two years of driving experience. And their average age is 24.8 years old. A questionnaire survey was “Do you like the styling of this car?”, using Likert Scale of −3 (No) to 3 (Yes). Statistics show the highest and lowest scores were 1.06 (Cruze) and −1.18 (Citroen C1). Respectively, these two car were chosen as training sample material (Fig. 2).

Fig. 2. Training samples

3.2 Eye Tracking Tests and Feature Extraction of Training Sample Selection

Equipment of the Test. The test equipment was a Dikablis head-mounted eye tracker manufactured by the company, Ergonieers of Germany. It worked in a monocular tracking mode to capture human left eye pupil by infrared camera. Before the test, the equipment was calibrated again by every participant. In experiment, the training sample pictures were presented in full screen on the 19 “monitor. The participants took the

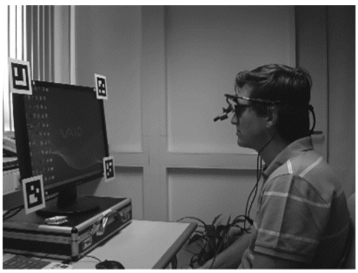

Fig. 3. Experimental scene

sitting posture and remained watching the display screen horizontally at a distance of about 90 cm. (as shown in Fig. 3).

Process of the Test. Atotal of 11 participants included 7 males and 4 females. After introduction about the purpose of test and the equipment, the participants were asked to watch the sample pictures for visual aesthetic for 15 s, and the eye movement result was processed by D-lab software.

3.3 Heatmaps Processing and Feature Extraction

The heatmaps of 11 participants were generated by software. Only one participant's heatmap is shown here in Fig. 4:

(No.1) ………………….(No.2)

Fig. 4. Heatmap of training samples

First, the heatmaps of training samples were stripped from the background meanwhile the color information were coded. Then, the color heatmaps were processed as grayscale images to obtain a histogram. The left heat map in Fig. 4 is taken as an example as shown in Figs. 5 and 6 after processing.

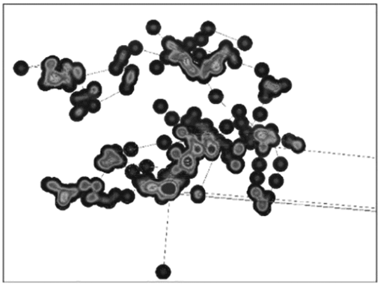

Fig. 5. Heatmap of training samples

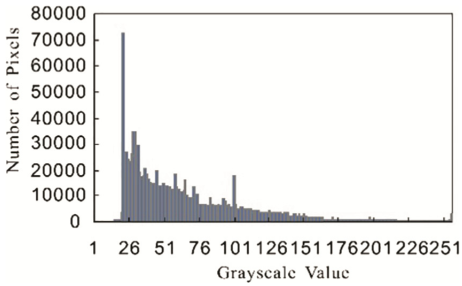

Fig. 6. Histogram of gray

The heatmap features of 11 participants were extracted, and the statistics calculated shown in Tables 2 and 3:

Table 2. Statistics calculated of Sample No. 1

	$X_1 = \mu$	$X_2 = \sigma^2$	$X_3 = \mu_S$	$X_4 = \mu_K$	$X_5 = \mu_N$	$X_6 = \mu_E$	$X_7 = K$
Participant 1	76.346	1788.728	0.716	–0.486	0.008	7.155	208.956
Participant 2	79.026	2129.913	0.810	–0.278	0.008	7.253	204.916
Participant 3	78.364	2043.521	0.881	–0.027	0.008	7.247	204.922
Participant 4	79.672	2119.298	0.653	–0.595	0.008	7.274	201.987
Participant 5	78.162	2061.861	0.648	–0.596	0.008	7.270	204.800
Participant 6	79.783	1946.110	0.703	–0.403	0.008	7.253	204.865
Participant 7	72.196	1734.479	0.747	–0.514	0.009	7.112	211.551
Participant 8	85.691	2230.868	0.444	–0.792	0.007	7.354	195.052
Participant 9	75.153	1853.770	0.731	–0.427	0.008	7.168	209.516
Participant10	69.907	1841.278	1.067	0.499	0.009	7.104	208.741
Participant11	67.869	1675.367	0.979	0.238	0.009	7.047	214.489

Table 3. Statistics calculated of Sample No. 2

	$X_1 = \mu$	$X_2 = \sigma^2$	$X_3 = \mu_S$	$X_4 = \mu_K$	$X_5 = \mu_N$	$X_6 = \mu_E$	$X_7 = K$
Participant 1	71.672	1777.848	0.822	–0.147	0.008	7.134	214.830
Participant 2	76.022	2102.735	0.686	–0.328	0.009	7.196	201.925
Participant 3	75.403	1790.197	0.570	–0.523	0.008	7.160	207.962
Participant 4	72.638	1997.063	0.724	–0.391	0.008	7.165	209.644
Participant 5	76.849	1799.905	0.536	–0.554	0.009	7.149	204.490
Participant 6	84.029	2209.908	0.514	–0.664	0.007	7.355	200.821
Participant 7	72.214	1690.260	0.742	–0.194	0.008	7.143	212.836
Participant 8	73.551	2065.443	0.788	–0.256	0.008	7.185	203.025
Participant 9	72.778	1574.610	0.627	–0.456	0.008	7.114	217.732
Participant10	75.336	2266.348	0.767	–0.257	0.008	7.245	201.653
Participant11	73.065	1978.316	0.892	0.130	0.009	7.175	206.489

According to the research framework above, with the statistics in Tables 2 and 3 by Fisher discriminated, the discriminate function was constructed as:

$$\begin{aligned} d(X) = -0.755X_1 + 0.009X_2 - 36.676X_3 + 9.960 \\ X_4 + 2707.174X_5 + 39.319X_6 + 0.364X_7 - 310.079 \end{aligned} \tag{7}$$

Compared with the results of 7-point Likert scale (−3~+3), no significant difference existed. So, that indicated the method was feasible.

4 Conclusions

A method of Auto form evaluation based on eye tracking is proposed. The Experiment result showed that overall accuracy of this method was high. So a feasible technical approach for the rapid evaluation of automotive styling is provided.

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