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Overall Cognitive Consistency of Complex Combination Form

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Abstract: *The work aims to study the formal aesthetic consistency of car body and wheel matching. An "aesthetic matching threshold method" was proposed. Taking the SUV model as an example, the clustering analysis of sample A was carried out by a k-means clustering algorithm to find out the cluster of typical samples in dealing with the cognitive consistency problem of model A and wheel type B. The morphological analysis of part B of the cluster was carried out to find out the typical characteristics of the influential design factors of part B. Based on the corresponding analysis, through the perceptual experiment, the design features were analyzed to find out the AB matching range. Through the experiment, six influential wheel hub design feature ranges were obtained, and the perceptual score range that reflected the SUV model and the hub matching was obtained by the perceptual experiment. In this range, model A and hub B were more harmonious regarding the visual aesthetics of matching. The proposed best aesthetic matching threshold method can be used to study the matching relationship between complicatedly combined products and their matching quality to help designers, businesses or individuals find suitable solutions.*

Keywords: *Product design; Morphological matching; Overall cognition; Participatory experiments*

1. Introduction

In recent years, customizing auto parts has become fashionable. The wheel hub, which has the largest surface area on the side of the body, has a strong impact on the aesthetics of the whole car, and the aesthetic issue of wheel and car matching has become the focus of attention[1]. At present, there is a lack of scientific and detailed matching methods between the car and the wheel hub, resulting in customized results that deviate significantly from the initial assumption.

With the trend of multi-discipline integration and development, the comprehensive application of each discipline's methods has become an important means and approach to enhance and improve the connotation of their respective discipline systems and promote the development of their own disciplines[2]. Through investigating, there are many factors that affect perception: Chen Hui considered the perceptual matching of clothing from the perspective of color[3]; Wu Xia asked consumers to conduct perceptual image scoring experiments on the material collocation of thermos cups through visual perception, to explore the corresponding relationship between the material collocation and perceptual imagery of each sample, and to provide designers with a reference for product material collocation design[4]; Zhou Hong-tao considered the perceptual collocation in Chinese furniture design from the perspective of style[5]. Researches on matching: Chien-Cheng Chang used hierarchical grouping tasks and semantic difference experiments to study the relationship between the form and visual matching of digital camera styling design elements. Shi-Jian Luo et al. created a list of design rules for each category of beverage bottles by performing a classification task and SD evaluation on 60 beverage bottle shapes to obtain a correlation analysis of subjects' perception of stimuli and matching. In the aspect of wheel hub modeling, Sun Li proposed the aesthetic structure and modeling gene characteristics of the "V-shaped memory curve" in the study of aluminum alloy wheels, and obtained the relationship between the wheel hub style image and modeling elements by using the method of perceptual engineering. Wu Jian-tao et al. obtained the optimal design factor combination method of wheel hub shape through the Taguchi method[6]. Cao Bao classified the style of the wheel hub and conducted research on the shape design through the visual vocabulary book.[7]

The shape of the wheel hub is more important in automobile design, but at present, there are few

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studies considering the aesthetic matching of wheel and car from the perspective of shape, and most of the cognitive research on form matching is still in the aspect of the perceptual intention between a single product and users. There is very little research on the components of complex combined forms and almost zero in terms of wheel-car matching. Therefore, in order to provide a reasonable suggestion for wheel hub customization, a design method for wheel-car matching based on user perception is proposed here. By applying this method, the overall cognitive consistency of wheel-car form matching is investigated.

2. Wheel and Car aesthetic matching threshold method

The "2016 China Automobile Industry Development Report" pointed out that the current development trend of China's automobile consumption market is multi-user and multi-purpose SUV models. With the advent of the era of personalized consumption, consumers have a hot demand for the customization of SUV models[8]. Therefore, the SUV model is taken as the research object here, and the wheel-car matching of the SUV car is studied through three steps.

2.1. Building a dataset of SUV models

SUV is a sport utility vehicle with neat lines and a slightly square shape, which is between a sedan and an off-road vehicle. In the current market, in order to make cars more selling, cross-border models are launched, which blurs the boundaries of model classification and causes errors in model judgment. Here, the k-means clustering algorithm is used to cluster and analyze 212 model samples, so as to find out the cluster of SUV models, avoiding the subjectivity and error of manual classification, and the cumbersome manual classification[9].

The k-means clustering algorithm can quickly cluster the samples. After verifying the accuracy of the clustering results, the typical SUV samples are classified by the nearest neighbor classification method, and the classic SUV samples finally are divided into SUV clusters.

2.2. SUV model samples have been equipped with wheel hub common feature extraction

Through the product morphological analysis method, the assembled wheels of the samples in the SUV cluster found in step 1 are analyzed according to the modeling factors from three aspects: component characteristics, spatial layout, and geometric characteristics[10], so as to identify the common characteristics of typical design factors. And these are the typical form features of wheels matched to SUV models on the market today.

When dealing with problems, the product morphological analysis method divides the research object into some basic components, and then deals with a certain basic component separately[11], provides various solutions to the problem separately, and finally forms a general solution to the entire problem.

2.3. Analysis of the typical form and characteristic range of the SUV model adapting wheel hub

In order to determine the aesthetic range of the wheel shape matched by the SUV model, step 3 conducts a corresponding analysis on the form characteristics of the typical SUV wheel hub found in step 2[12], and under the condition that the typical form characteristics of other wheel hubs remain unchanged, each factor affecting the wheel hub shape is analyzed. Change analysis was carried out, and a 7-level Likert scale was established. Through perception experiments, subjects were invited to score and rank the aesthetic degree of wheel and car perception matching, and finally obtained the critical value of aesthetic matching.

The judgment of aesthetic matching comes from the subject's perception, and that is, perceptual perception. Through user ratings, positive and negative formal features can be identified to find aesthetic thresholds for SUV wheel-car matching.

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3. Experimental procedure and result

3.1. Graphical filter

Before the start of the experiment, samples of SUV models and wheel types with typical characteristics were established firstly, which are: The SUV model A1 with the highest sales in the past 3 years (HAVAL H6, from the data officially released by Sohu Motors in 2016) and the SUV sample A2 with the highest styling evaluation (Land Rover Discovery, from the word-of-mouth rankings officially released by Sohu Motors in 2016), as well as the wheel type sample B1 with the highest sales volume for SUV models (AEZ dark yacht wheel, the source is the No. 1 sales volume of SUV wheel modification provided by Tailing hui's official website), and a typical example configuration file is shown in Table 1. Then, 200 sideways pictures of different types of cars are randomly selected from the official websites of each brand of the automobile as samples to form a random model sample library A (A3, A4, ... A202).

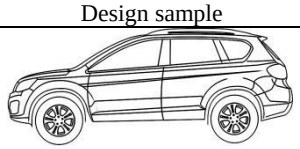
After the model samples A1 and A2 are determined, three wheel types with the highest matching degree in the market are respectively found, and the samples A1B1, A1B2, A1B3, and A2B1, A2B2, A2B3 are composed as typical wheel type samples. And the first 3 models on the market that match the wheel type B are also found, consisting of samples BA1 (Audi Q7), BA2 (Porsche), and BA3 (Touareg).

In order to conduct research from the aspect of morphology more clearly, the 212 samples obtained are processed uniformly through photoshop software here[13], and factors irrelevant to the sample research, such as color, material, etc., are deleted, and the modeling factors are only retained so that computers and the subjects can conduct research more intuitively and get accurate experimental results.

3.2. Building a dataset of SUV models

A total of 3 tests were carried out, and the chassis height, body height, and vehicle outline were taken as the main features to distinguish the types of cars. The results show that the accuracy of clustering through the outer contour of the body reaches 85%, and the effect is better than others. Therefore, the classification of car models from body contours will be studied, and the following is a detailed introduction.

Table 1: A typical example configuration file

Sample	Description	Representative car	Design sample
A1	The SUV model with the highest sales in the past 3 years		
A2	The SUV sample with the highest styling evaluation		
B1	The wheel type sample with the highest sales volume for SUV models		

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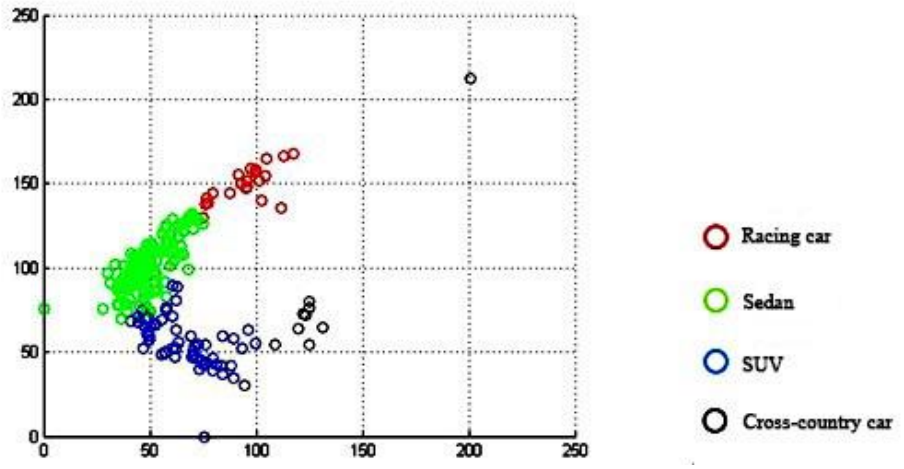

Figure 1: Model classification results

The 209 car model samples (50 of them have marked samples, the purpose is to test the effectiveness of feature selection) are binarized through MATLAB, the outer contour of the model is extracted, and the Pearson correlation coefficient between the samples is calculated to obtain the similarity matrix. The models are clustered using the K-means clustering algorithm. Finally, the typical samples are classified according to the nearest neighbor classification method. After multiple experiments, the samples were finally divided into 4 clusters, and the model classification results are shown in Figure 1.

The classification result indicates that A1, A2, and B are in the same cluster, indicating that the model cluster representing the SUV has been determined and marked as 3 in MATLAB. After sorting, the SUV models are summarized. From the summary results, it can be seen that the models in cluster 3 are similar but the wheel types are different.

3.3. SUV model samples have been equipped with wheel hub common feature extraction

In this experiment, the wheel types of the sample clusters were first summarized, and the summary of the SUV wheel types is shown in Figure 2, and then the product shape analysis method was used to analyze the wheel shapes, and the wheel shape analysis is shown in Figure 3. During the analysis, 5 senior wheel designers from the local area were invited as experts. Through careful analysis by the expert group, the typical form characteristics of each sample wheel type were identified.

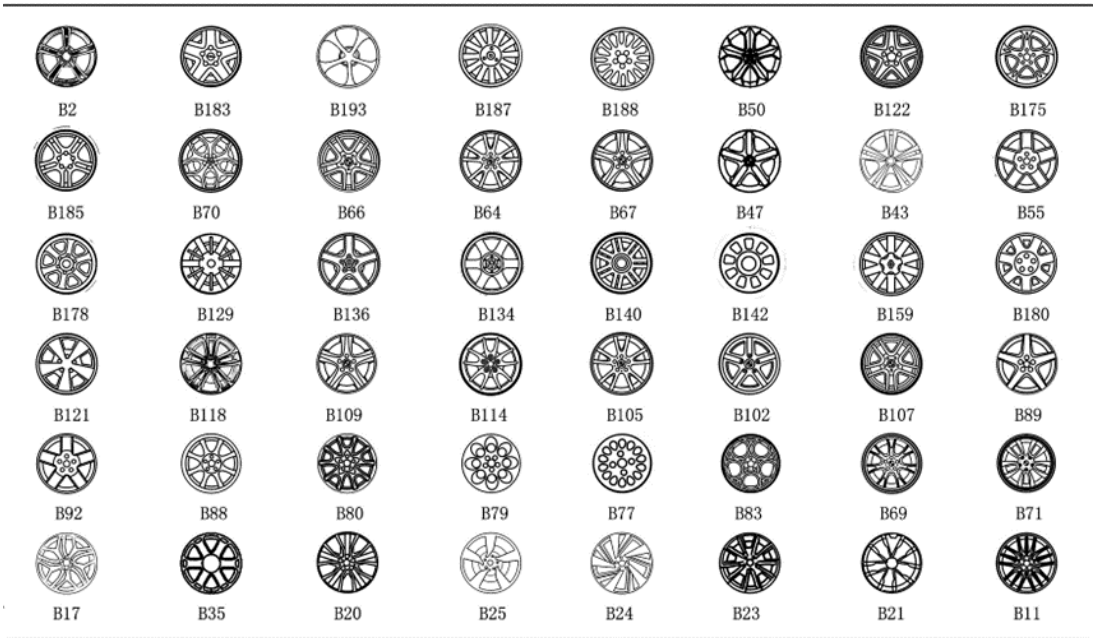

Figure 2: SUV wheel type summary

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3.3.1. Wheel shape analysis

The important component feature is the number of spokes; the spatial layout and composition methods include conventional, rotating, branch, stacking, and hole types; the center offset includes positive offset, zero offset, and negative offset; the connection methods of spokes and rims include overlapping and inscribed; geometric features of spoke styles are triangular, square and round; spoke connection methods are pointed, curved and straight.

Through the morphological analysis of the sample wheel types in cluster 3, the morphological characteristics of typical wheel type designs based on SUV models in the current market and the approximate matching critical value range are summarized. It is preliminarily considered that the shape design of the wheel hub based on SUV models should meet the requirements of the number of spokes ranging from 5 to 8 spokes, the composition method of conventional type/branch type, the central rim surface of flat/concave, and the connection method of spokes and rims to be lap/inner. The common features of the inlay, the spoke-style are square/triangular, and the spoke connection method is sharp/arc angle. On the contrary, the number of spokes is less than 5 spokes and more than 9 spokes, and the structure is reversed such as rotation or holes. We think this may not be suitable for SUV models. In order to verify the accuracy of the experimental results in 2.3 and find the exact range of the final aesthetic critical value, further analysis is required.

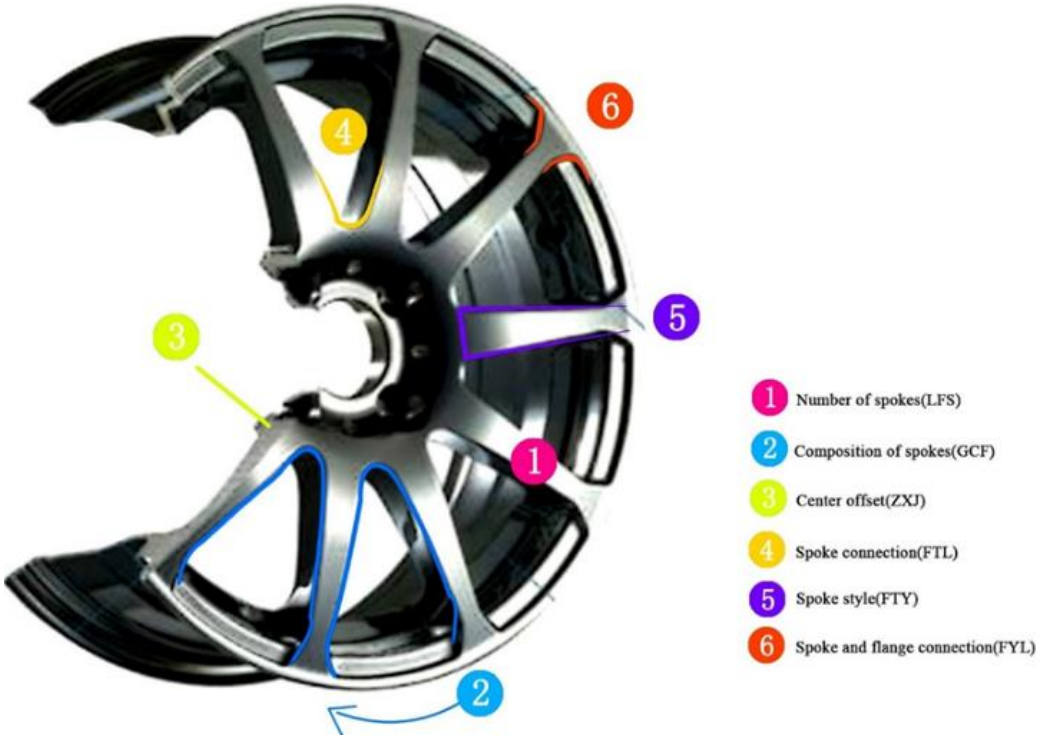

Figure 3: Wheel analysis

3.4. Analysis of the typical form and characteristic range of the SUV model adapting wheel hub

According to the common feature extraction task in 2.3, the typical wheel design features of SUV models can be identified. This program is based on the found typical design features, through correspondence analysis and perception experiments to obtain the morphological matching critical value[14].

This test provides sample A2 of the most popular SUV models in China in the past three years; typical wheel design sample (change the design variables to be studied under the condition that other typical design variables remain unchanged); subjects, 20 users with SUV cars (14 males, 6 females, average age 35 years old), they selected according to the following characteristics: (1) at least 3 years of driving experience; (2) white-collar class, these characteristics are the most representative typical young Chinese driver.

3.4.1. Research on the aesthetic critical value of different spoke styles

As an important factor affecting the design of the wheel hub, the spoke style plays a vital role in

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wheel-car matching. Different spoke styles bring people different perceptions. The spoke-plate spokes give people a stable and solid feeling, and the spoked spokes give people light and fast perception. According to the morphological analysis results of the wheel hub in 2.3, in this test, the wheel spokes are analyzed from 3 morphological categories: triangle, circle, and square. A total of 13wheel samples are built to study the matching quality ranking of different spoke styles.

The experimental results show that, by analyzing the matching scores of 20 subjects, it is found that when studying the morphological characteristic of spoke pattern, the matching quality appears in a tie. According to the degree of satisfaction from high to low, the matching quality of the hub is identified, and three groups with the worst matching quality can be found, namely: convex square, concave curve equilateral triangle and circle. In addition to these three spoke styles, the matching scores of other spoke styles and SUV models are all above 0, which indicates that the matching threshold of the spoke styles that conform to the user's psychological fit is in addition to these three methods. The summary is as follows: Inverted triangle (single-spoke straight line, concave curve, double-spoke straight line, convex curve), square (single-spoke straight line, concave curve, double-spoke straight line) and equilateral triangle (single-spoke straight line, double-spoke straight line, convex curve). Among them, inverted triangle and square are the highest aesthetic point of SUV spoke style, and straight-line and concave curve are the most popular spoke forms.

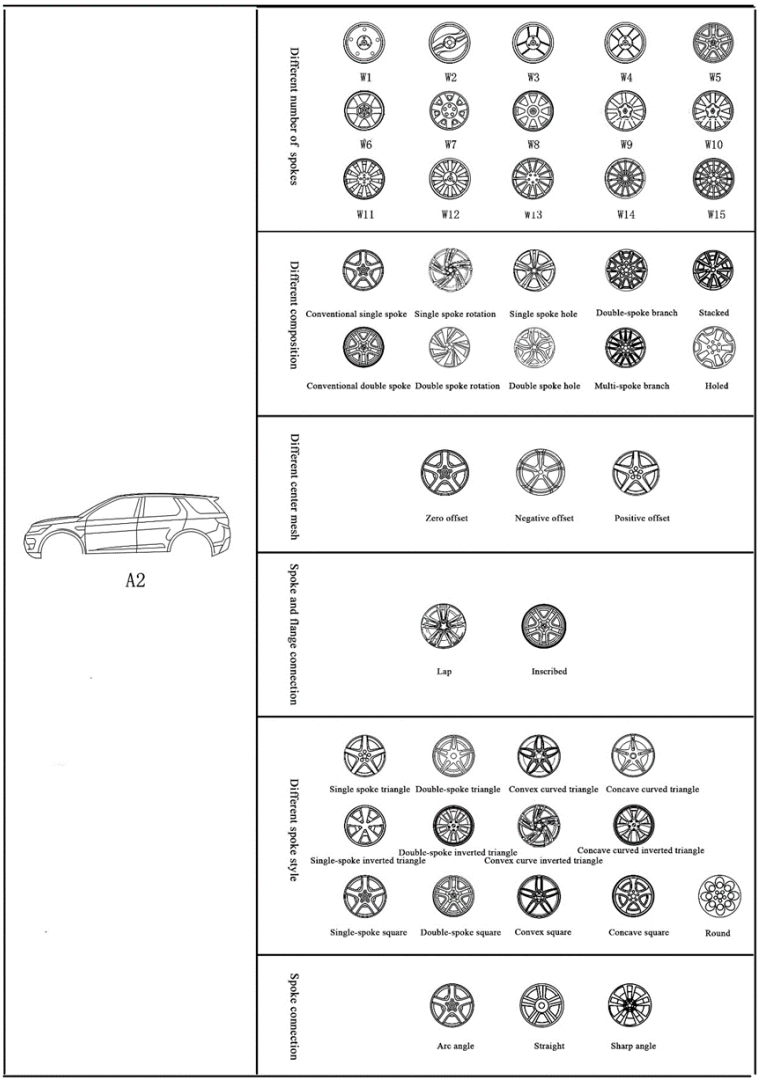

Figure 4: Corresponding analysis of wheel type characteristic

3.4.2. Identifying the Spoke Connection Method Suitable for SUV Models

The matching quality ranking of different connection methods is shown in Table 2. It can be seen from the table that the matching average value is too close. After careful analysis by the expert group, it is believed that the feature of the spoke connection method has little influence on the design of the hub.

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It doesn't make sense to study how the spokes are connected in isolation, and it should be analyzed under the form changes of other design features. Therefore, we summarize the results of the change of spoke connections under different morphological characteristics by taking the wheel types with high evaluation based on user perception matching in 2.4 as samples: (1) The change of the spoke connection method under the characteristics of the number of spokes, through the study of the samples, it is found that when the number of spokes is large, the morphological matching of the sharp angle makes the overall appearance of the hub more harmonious. When the number is small, the arc angle design can make the wheel shape look more beautiful; (2) The change of the spoke connection method under the characteristics of the composition method, through the analysis of the samples with high matching scores in the composition method research samples, it is believed that the conventional wheel hub composition method matches the arc-angle spoke connection method is more harmonious, and similarly, it is more harmonious to match the sharp-angle type with the structure of the branch and rotating hub; (3) The change of the spoke connection method under the spoke-style feature, through the analysis of the excellent samples in the spoke-style feature, it is found that the straight spoke-style has a good matching quality for different spoke connection methods, but the curved spoke style is only suitable for the structure of the arc angle type. Therefore, the spoke connection methods suitable for SUV models can be summarized as multi-spoke sharp angle type, conventional arc angle type, branch sharp angle type and curved arc angle type.

Table 2: Matching quality ranking of different connections

Spoke connection（FTL）	Average score	Subject number																			
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20
FTL=Arc angle type	1.30	2	1	1	2	2	1	0	1	0	2	2	1	1	2	2	1	0	1	2	2
FTL=Right angle type	1.05	-1	2	1	1	2	2	1	0	1	0	2	2	1	1	2	2	1	0	1	0
FTL=Sharp angle type	1.10	2	-1	2	0	2	1	1	2	2	1	1	1	1	2	0	2	1	1	1	0

3.5. Result

With the corresponding analysis of typical design features, the matching critical value of wheel shape features based on SUV models was successfully found. Through analysis, it is found that among the features that affect the design of the wheel hub, the number of spokes and the pattern of the spokes account for a large proportion. The critical value of the aesthetic matching of the number of spokes based on SUV models should be between 5 spokes and 11 spokes, and the spoke patterns are dominated by triangles and squares, with straight and concave curves being the most popular forms of spokes. The spoke pattern specifically includes inverted triangle (single-spoke straight line, concave curve, double-spoke straight line, convex curve), equilateral triangle (single-spoke straight line, double-spoke straight line, convex curve) and square (single-spoke straight line, concave curve, double-spoke straight line). For other features that affect the shape of the wheel hub, they have been analyzed in detail here. When doing the wheel-car matching, these influential design features should be fully considered, and the wheel-car matching should be carried out according to their own conditions.

3.6. Design inspection of wheel hub based on SUV models

Based on the above research methods, here, taking HAVAL H6, which has the highest sales volume in the past three years, as an example, two opposite wheel shapes are designed to match the SUV hub modeling design within the matching threshold as shown in Figure 5, and on the contrary, the SUV hub modeling design beyond the matching threshold is shown in Figure 6. Through the evaluation and analysis of the two schemes, the subjects believe that Figure 5 is more suitable for SUV models than Figure 6, and the score results are 1.8 and 0.6 respectively, which indicates that the wheel-car matching research method here has a certain reference value.

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Figure 5: SUV hub modeling design within the matching threshold

Figure 6: SUV hub modeling design beyond the matching threshold

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References

[1] WU Jian-tao. Based on the Pixel Shape Design Method and Its Application Research [D]. Qinhuangdao: Yanshan University, 2016.
[2] DU Wei, CHEN Heng. Interdisciplinary Study: The Strategic Selection of the Discipline Construction in Application-oriented Institutions [J]. Higher Engineering Education Research, 2012(1): 127—131.
[3] CHEN Hui. Clothing Color Matching Research [J]. Dyeing and Finishing Technology, 2016(11): 6—20.
[4] WU Xia. Research on Collocation Design of Product Based on Perceptual Intention of Consumers [D]. Hangzhou: Zhejiang University, 2010.
[5] ZHOU Hong-tao. Research on Innovative Design of Chinese Concept Furniture [D]. Haerbin: Dongbeilinye University, 2005.
[6] CHIEN C. Factors Influencing Visual Comfort Appreciation of the Product Form of Digital Cameras [J]. International Journal of Industrial Ergonomics, 2008(38): 1007—1016.
[7] LUO Shi-jian. Perceptual Matching of Shape Design Style between Wheel Hub and Car Type [J]. International Journal of Industrial Ergonomics, 2012(42): 90—102.
[8] SUN Li. Technical Aesthetic Foundation and Application of Aluminum Alloy Wheel Design [D]. Qinhuangdao: Yanshan University, 2014.
[9] WU Jian-tao, CHEN Yong-liang. Study on Optimization Design of Aluminum Alloy Wheel Shape Based on Taguchi Method [J]. Journal of Yanshan University, 2015(6): 531—534.
[10] CAO Bao. Based on the Style Description of the Wheel Design Method [D]. Qinhuangdao: Yanshan University, 2013.
[11] FU Yu-wu. 2016 China Automotive Industry Development Report [R]. Beijing: China Society of Automotive Engineers, 2016.
[12] JIANG Yan-huang, ZHAO Qiang-li. Machine Learning Method [M]. Beijing: Electronic Industry Press, 2009.
[13] CHEN Yong-liang. Wheel Intelligent Form Correction System Design and Research [D]. Qinhuangdao: Yanshan University, 2015.
[14] WU Jian-tao, ZHAN Yuan. Application of Orthogonal Experiment in the Exterior Design of Exercise Bike [J]. Packaging Engineering, 2014, 35(24): 54—58.