Product Family Shape Based on Similar Characteristics

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***Abstract*—Product family is the core of mass customization that can provide personalized product for customers. The existing product family includes moderation-based and scale-based product family. Both of them suit to the products in pursuit of technique and function but not to shape and aesthetic perception. In this thesis the concept of product family shape atlas is presented and the corresponding method is explained to realize the shape automatic categorization and retrieval. Firstly, based on similar shape characteristics, the samples are classified and a preliminary model of product family shape atlas is established. And then the computer technology is used to realize the automatic categorization by simplifying the massive sample pictures and comparing geometry similarity. Finally, the spectral shape library of wheel hub is taken as an example to demonstrate the feasibility and superiority of the presented method.**

***Index Terms*—Product family shape; Shape feature; Picture simplification; Similarity; Automatic categorization.**

I. Introduction

The fundamental causes of mass customization design stem from commodity competition, buyer's market and different requirements for products. Mass customization is close to mass production at costs and efficiencies but provides the customized products or services to satisfy individual needs, and its implementation platform is to build a product family [1].

At present, the studies on product family mainly focus on two categories: modulation-based and scale-based production family design [2], both of which lack controls on products gestalts [3].

Therefore, this paper puts forward the establishment of product family shape library which includes the different forms and gestalts of products at maximum degree. For computer-aided design [4] in visual identification, the method of shape similarity [5] algorithms should be used.

The method of moderation-based production family is studied in detailed in references [6-10], which includes "platform plan", simultaneous optimization for system structure and configuration of production family, improving the product flexibility by using standardization researched, and the architecture method FPA for product family.

The scale-based production family design method mainly includes robustness concept exploration method RCEM [11], product platform concept exploration method PPCEM [12], the Variation-Based Platform Design Method VBPDM [13], and the optimization design for product family based on genetic algorithm [14].

The premise of module partition and plateform are based on the clear quantitative indicators, such as materials, processings, structures and etc.

Compared with the previous studies, building product family shape which we present is expected to be more enlightening in the mass customization area, especially to the fuzzy, changeble and individual aesthetic perceptions.

First, the establishment of a Preliminary Model is introduced. Then, the computer algorithms are used to simplify the picture and the similarity is compared among the geometries. And last, the automatic categorization of massive sample pictures is ultimately achieved. The sample is classified with the general characteristics of skeletal lines and detailed change rule to establish a tree-shaped spectral library of product family model initially.

II. Establishment of a Preliminary Model

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A. *Concept of Product Family Shape*

Product family shape is a produce tree that divides and classifies products based on external form characteristics layer by layer. It has multiple levels, and each of them contains some subsets. Similar geometric shapes are classified into a subset. Since the product structures are different, their forms are different too. The internal structure, function and other factors will affect its external manifestation. Showing them through the external form can bring intuitive visual effects, which helps customers to choose the product satisfying their needs from the shape library.

B. *A Preliminary Model of Product Family Shape*

in Fig. 1 and Fig. 2, The building process of product family shape and preliminary model are shown respectively.

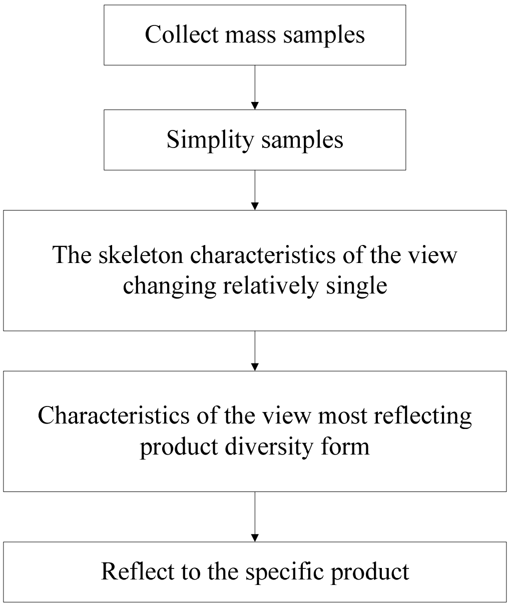

Figure 1. Process of product family shape.

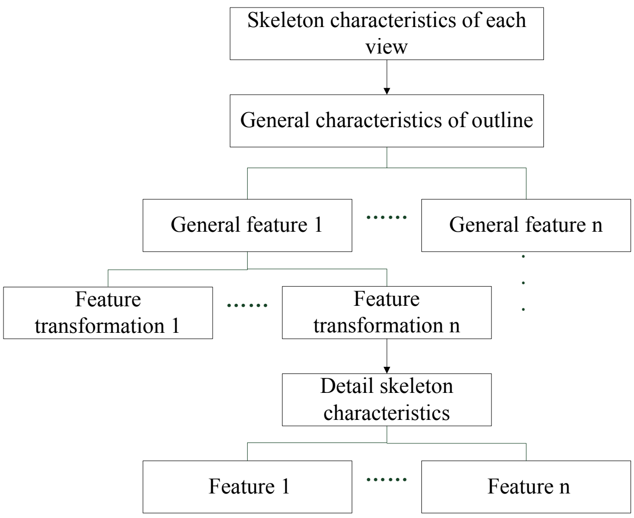

Figure 2. Preliminary model

The establishment of product family shape is a process from concrete to abstract, and then from abstract to specific. The process can be described as follows: firstly collect a large number of product sample pictures as comprehensively as possible; secondly abstract specific graph into a refined form of lines; then classify products with the general characteristics of outline according to the principle from simple to complex and from local to overall, which starts from the view of relatively single skeleton change, and ends with the view of the most able to reflect product diversification form; finally divide layer by layer on the basis of differences in details, such as line property, angle change, and map to the specific product shape.

III. Automatic Classification of Sample Picture

After a preliminary shape model being established, the computer technology is used to simplify the sample pictures into abstract geometric shapes, and the image is automatically put into the category with higher similarity by making similarity comparison with templates step by step.

A. *Picture Simplification*

In Fig. 3,the specific process of simplifying picture is shown.

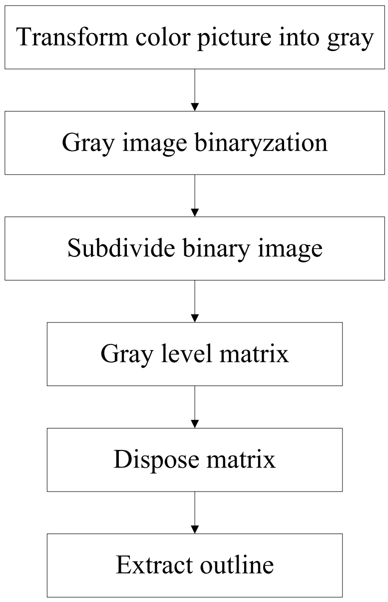

Figure 3. Specific process of simplifying picture

The sample picture simplification is the premise of making geometric shape similarity comparison with templates. Firstly, the color image is changed into the gray level which only contains brightness information without any color. Through calculating the mean for three components R, G, B of each pixel point and distributing the result to each component, the color picture becomes a gray image [15].

Secondly, the binaryzation processing[16] is conducted, that is to say, the gray values of image points are set as 0 or 255, so the whole picture only presents black and white effects. The key to binaryzation is the threshold.

The pixel gray value that is greater than or equal to the threshold is set as 255, appearing white, otherwise is set to 0, appearing black. OTSU [17] is used to automatically select the threshold, and the specific algorithm is described as follows: the image has L gray values. By taking any number *x* between 0 and L-1, the image is divided into two groups K_1 and K_2. The range of gray value K_1 is from 0 to *x*, and K_2 is from *x*+1 to L-1. M is the total number of pixels, m_i is the number of gray level i, then Probability for each gray level value i is

$$P_i = m_i / M \ . \quad (1)$$

Probability for K_1 and K_2 is:

$$w_1 = \sum_{i=0}^{x} P_i \ , \quad w_2 = \sum_{i=x+1}^{L-1} P_i = 1 - w_1 \quad (2)$$

The mean of K_1 and K_2 are :

$$u_1 = \sum_{i=0}^{x} iP_i \ , \quad u_2 = \sum_{i=x+1}^{L-1} iP_i \quad (3)$$

Inter-class variance:

$$\sigma(x)^2 = w_1 w_2 (u_1 - u_2)^2 \quad (4)$$

Following the steps (1)-(4), inter-class variance could be obtained. When the value is the maximum, number *x* is the threshold.

In the end, the 8-neighborhood labeling algorithm is used to extract an outline [18]. The Binary image is divided into small cells, each of which is a point and only displays one color (black or white). Set the black as number 1 and the white as number 0. Scanning the whole image, an m×n gray level matrix is eventually formed. The gray level matrix is processed according to the following rules. If the eight directions(up, down, left, right, upper left, lower left, upper right and lower right) of number 1, are all number 1, which indicates the point is internal, then number 1 is changed into 0; But if any direction shows as number 0, which suggests outside, then number 1 is still remained. Deal with the matrix with this order, and remove all the points displaying 0. The rest will compose the outline, thus the picture is simplified into a refined line form.

B. Geometric Feature Similarity Comparison and Classification

When the closed geometry graph is transformed into a unique corresponding curve, the graph similarity can be achieved by comparing the curves similarity.

a. Transforming the closed outline into a unique curve

In Figure 4, scanning graph is needed for a unique curve. A closed outline can be obtained by picture simplification. Using the graphic center of gravity O as origin, a rectangular coordinate system could be established. If we draw a ray J from the origin, and scan the graph from θ=0° to θ=360°, then the distance L of each scanning position from the origin to the outline is recorded.

Figure 5, a characteristic curve. The characteristic curve can be established with X=θ and Y=L, which can be used to represent the features.

According to the principle of characteristic curve, x is in the range from 0 to 2π. Because the origin of the coordinate system is the center of gravity of the graph, the translation does not affect operation. Computing the average height of curves in contrast which we name h1 and h_2, | h_1- h_2| is the adjustment quantity of the Lower height curve and it will also eliminate the influence of size on the calculation. Since the Image rotation would cause certain interference to the operation, so we define the starting position for scanning. The closest point to the origin is the right position, where we define θ=0, therefore, the rotation effect of the image is eliminated.

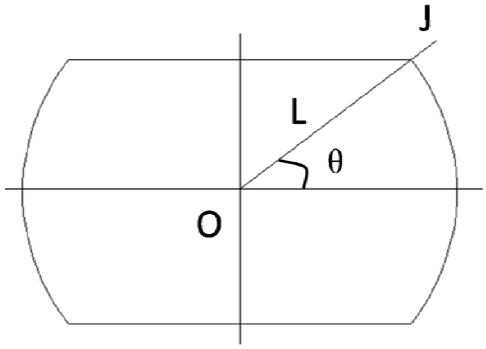

Figure 4. Scanning graph

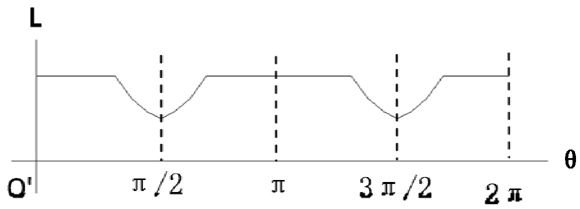

Figure 5. Characteristic curve

b. Extraction of curve characteristic parameters

Curve features include symmetry, continuity, cycle, inflection point number, concave and convex curve. Through the fitting of characteristic curve, characteristic function could be obtained. By analyzing the function, several curve characteristics can be known as below:

Symmetry:

Symmetry includes axial symmetry and center symmetry, and the mathematical functions can be expressed as follows: f(a-x) = f(a + x) or f(a-x) = -f(a + x).

Periodic:

Period is an important characteristic of graphic expression, which can effectively shorten the research scope of curve. For a regular graphic, the periodic inconsistency illustrate that they are not similar. The period can be expressed as f(x)=f(x+n*T) (n=0, 1, 2...). This calculation method is easy to implement in computer language.

Convexity of the curve:

Taking any two points on the graph of function f(x), if the middle segment of the function graph between the two points is always under the line which is built by connecting the two points, it is a concave function, otherwise, it is a convex function. The function can be expressed in mathematical functions in the following equation:

$f(\lambda x_1+(1-\lambda)x_2)<=\lambda f(x_1)+(1-\lambda)f(x_2)$ "V"shape

$f(\lambda x_1+(1-\lambda)x_2)>=\lambda f(x_1)+(1-\lambda)f(x_2)$ "A"shape

Inflection points number:

Inflection point in math refers to the point of changing curve upward or downward direction [19]. If the function of curve graph in the turning point has the second derivative, the second derivative is zero or it does not exist.

According to the following steps, we can distinguish the turning points of continuous curve y = f (x):

(1) Calculate f''(x);

(2) Define f'(x) = 0, work out the real and Invalid solution of the equation in interval "I";

(3) Calculate each real root or Invalid point x_0 of second derivative according to step 2. Check neighboring symbols of f''(x) on both side when $x=x_0$. If the two sides of the symbols are opposite, we can say the point is a turning point. Otherwise, the point is not a turning point.

c. Similarity comparison

The concept of similarity is that a curve can get another curve through translation, rotation and geometric scaling (including images). The eigenvalue method or the Euclidean distance method is applied to compare similarity of curve. If two diagrams do not have the same characteristics, it can be concluded that the two figures are not similar. So these methods can be used to contrast the two diagrams hierarchically, which reduces the amount of calculation and improves operation speed.

If the diagrams are similar, the distance of corresponding points must be as close as possible. To compare the two figures, the slope is computed by uniformly selecting 100 points from different angles. The smaller the slope is, the more similar the two figures are. The calculating formula can be expressed as follows:

$$D(x)=\sqrt{\sum_{i=1}^{100}[f_1(x_i)-f_2(x_i)]^2} \tag{5}$$

where D represents the similar degree, and f1(xi),f2(xi) are the two function curves. The closer to 0 the value D is, the more similar the two curves will be.

By comparing the periodic, symmetry, number of inflection points, concave and convex of graph orderly, the graphics are selected step by step. By contrasting the sample with the temples in product family shape library, the automatic classification of pictures is realized.

IV A Case Study on Shape Library Establishing and Completing

A. A Preliminary Model of Wheel Shape Library

A wheel can be divided into disc, mesh and spoke type according to its structure type. In addition, the spoke wheel is subdivided into above seven and below seven in accordance with the number of spoke. Since the wheel structures are different, their skeleton line features are also different. Take the spoke wheel below seven for example to set up a preliminary shape model.

The skeleton line of a side view for the wheel hub changes is relatively simple, while the skeleton line of a front view is complicated, which is the best to present the diversity of product form. According to the principle from simple to complex, the skeleton characteristics of the side view is studied firstly, and then the front view.

In Fig. 6 and Fig. 7, the skeleton characters of side and front of the wheel hub are shown. Seeing the skeleton line of the wheel hub from the side view and taking the center axis as a reference, the wheels are divided into three forms: convex, parallel and concave, according to the general characteristics of the outline. Then refine each form step by step through changing the line property, bending degree, angle and so on. For the front view, the wheel hub can be divided into one, two, three, five and seven spokes based on the number. Then each spoke will be subdivided into two subsets: vertical and rotary type. Next, divide the subsets layer by layer in accordance with linear transformation. Finally, a preliminary shape model of wheel like a tree is established.

B. Automatic Classification of Wheel Sample Pictures

To realize automatic classification, the specific wheel sample must be simplified into an abstract line form. Then the sample is automatically classified as a group with higher similarity by calculating and comparing the geometric similarity.

a. Automatic Classification of Wheel Sample Pictures

Fig. 8 shows a specific operation and result for a wheel picture.According to the principle of simplifying picture discoursed above, any wheel picture can be processed in an abstract way.

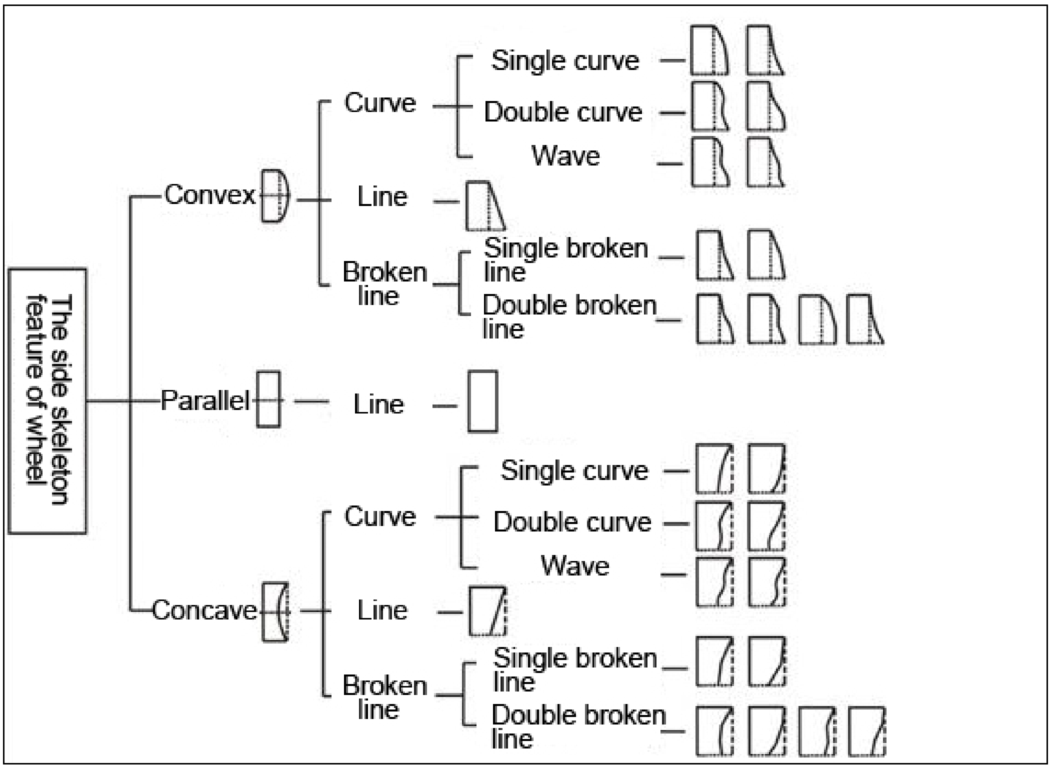

Figure6. Skeleton characters of side view

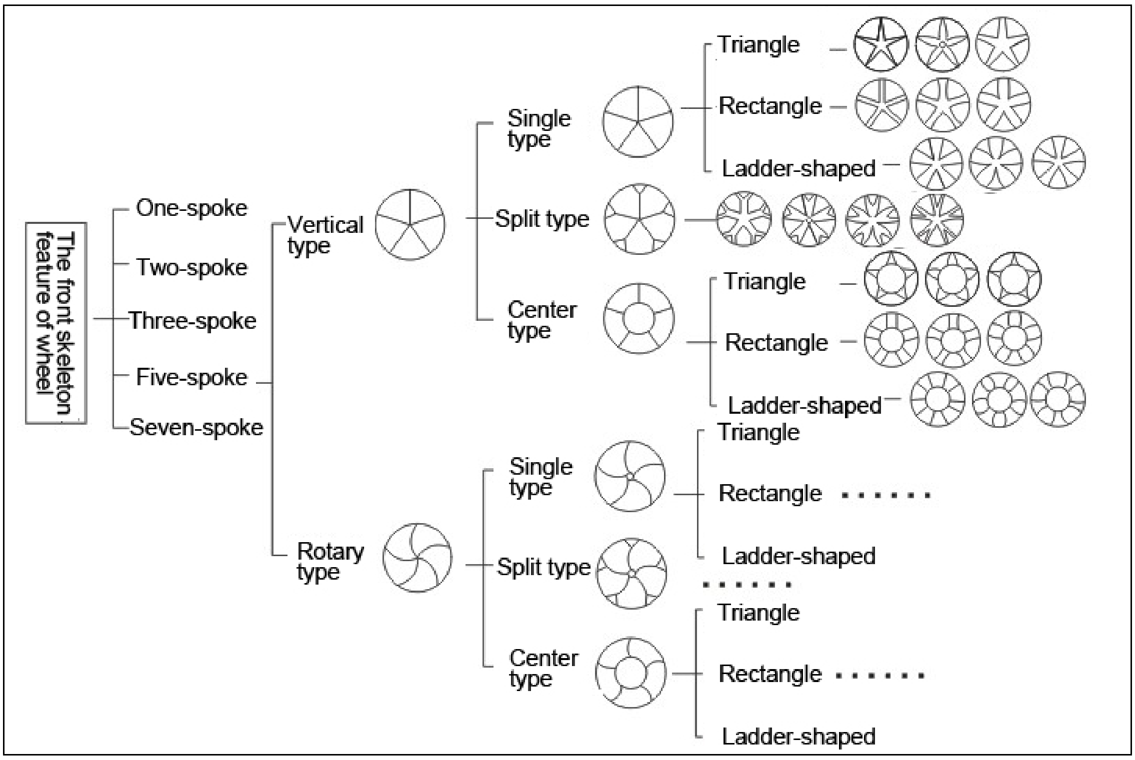

Figure7. Skeleton characters of front view

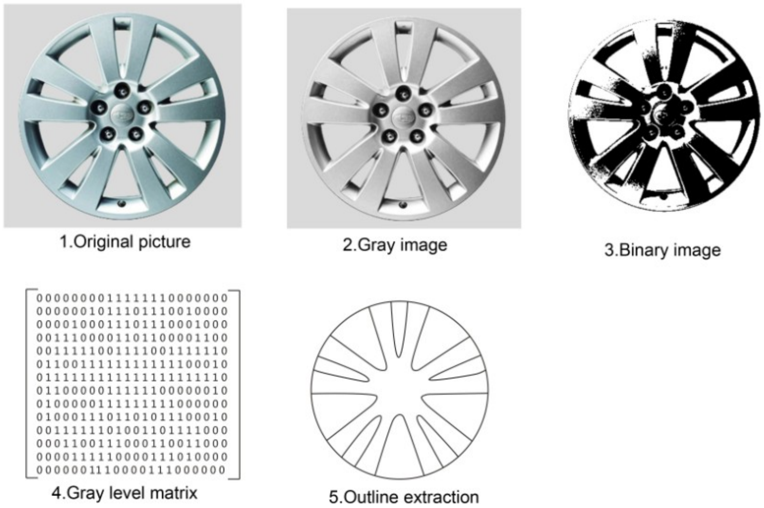

Figure 8. Process of simplifying wheel picture

b. Similarity Comparison and Classification

Many methods and technologies are developed to compare two images in similarity in references [20-22], which includes the partitional Clustering Techniques for dimension reduction being presented by Danielle Nuzillard and Cosmin Lazar, and the Intuitionistic fuzzy set theory based on the HSV color histogram being researched by Shaoping Xu et al. Conducted by Jian Wu, Zhiming Cui et al., the blocking contourlet transforming theory is also good to deal with strong texture characteristic.

Fig. 9 and Fig. 10 show the characteristic curve for the previous sample wheel. Here, Characteristic curve generating method is used to compare the similarity of curves. The steps are as follows: Select inner outline and set up a coordinate system whose origin is taken as the center of gravity, then scan the picture to obtain a characteristic curve.

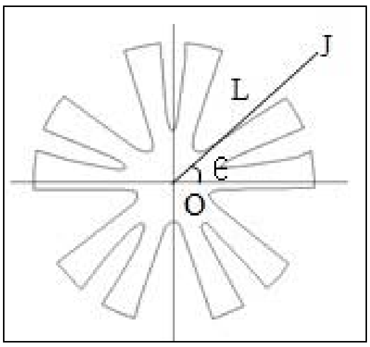

Figure 9. Scanning wheel graph

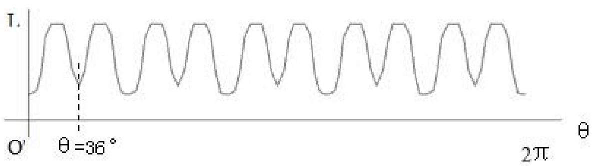

Figure 10. Characteristic curve of wheel

The characteristics are distinguished before comparing similarity with templates. From Fig. 9, we know the period T = 72, n = 5, so it belongs to five spoke wheel; in addition, the graph is symmetrical about θ=36° in a cycle as shown in Fig. 10, therefore it is a vertical wheel. There are five inflection points within a period in Fig. 9, and the properties are concave, convex, concave, convex, and concave. The pattern matching the graphic feature is the only split type as shown in Fig. 5.

Next, The curve features are compared. 100 points between 0 to 2π are uniformly selected to compare with the underlying temples as shown in Fig. 11. One of them is taken as an example as shown in Fig. 12. The graphic is scanned to get a characteristic curve shown in Fig. 13.

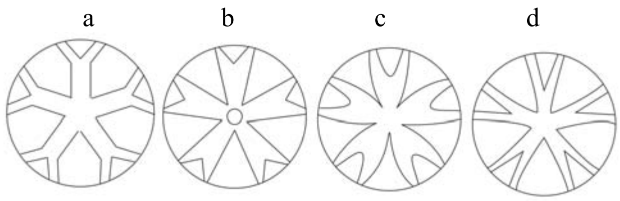

Figure 11. Wheel underlying temples

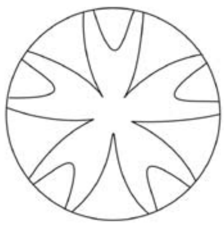

Figure 12. Wheel temple C

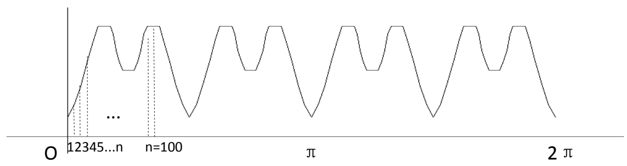

Figure 13. Characteristic curve of wheel temple C

V. RESULTS

The 100 points are equally selected from the previous two figures. Then similarity is calculated according to formula 5, and the following result is obtained.

$$Dc = \sqrt{\sum_{i=1}^{100} [f_1(x_i) - f_2(x_i)]^2} = 13$$

The similarity of other wheel temples compared with the sample is calculated in a same way, and the following results are obtained: $D_a=64$ 、 $D_b=32$ 、 $D_d=12$. This indicates that: The smaller the D value is, the higher the similarity will be, and thus the sample is classified as group d automatically.

VI. CONCLUSION

The method above changes the current inherent design pattern of product family which classifies the modules with function and is a new direction to the research of product family. Based on the method, a spectral shape library is established to create a product family shape which is more intuitive, more convenient, more friendly and has a significant value than other types of product family. First, the sample is classified with the general characteristics of skeletal lines and detailed change rule to establish a tree-shaped spectral library of product family model initially. Then, the computer algorithms are used to simplify the picture and the similarity is compared among the geometries to ultimately achieve the automatic categorization of massive sample pictures. Thereby the involvement of professional designers is reduced, the efficiency of spectral libraries is improved, and further the product family shaped spectrum model is optimized, which makes the shape of the product form library richer and more comprehensive and lays foundation for future practical applications at the same time. More product form in shaped spectrum of products can reduce the time and cost of research of new products and improve work efficiency because a production line can produce diversified products in parallel. More importantly, the graphics reconstruction with other shapes in the form template library can produce more new product form, which gives customers greater choice space and fully meets their personalized and customized needs.

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REFERENCES

[1] Dan Bin. Mass customization: build enterprise core competitive force in the 21st century [M]. Science Press, 2004: 19-23.
[2] Wang Yunxia,Tang Wencheng. Summary on the research of designing method for mass customization oriented product family [J].Journal of Machine Design, 2004, 21(6):1-4.
[3] Aron Gurwitsch. Studies in Phenomenology and Psychology [M]. translated by Fred Kersten, Evanstaon: Northwest University Press,1966:267-268.
[4] Yi Zhang, Sihui Mu. Study of Computer-Aided Design Process and Methods Based on Welding Fixture [J]. Journal of Computers, 2012,7(6): 1421-1428.
[5] Guimei Zhang, Jun Chu. Recognizing Partially Occluded Object from a Line Drawing [J]. Journal of Computers, 2011, 6(8):1740-1747.
[6] Messac A. Martinez M P. Simpson T W .Introduction of a product family penalty function using physical programming [J]. ASME Journal of Mechanical Design, 2002, 124(2):164-172.
[7] Jayier P Gonzalez Zugasti,Kevin N ott. Platform-based spacecraft design: a formulation and implementation procedure [J].IEEE, 2000 (10):455-463.
[8] Rebecca Duray, Peter T Ward .Approaches to mass customization: configuration and empiri-cal validation [J].Operations Management, 2000, 30(18):605-625.
[9] Bin S,Huang G Q,Mak K L.Web-based product platform development using graph theory[J].IEEE,2002(7):107-112.
[10] Xue Hongdu. Architecture of product family for mass customization [J].IEEE, 2000(9):437-443.
[11] Simpson T W; Chen W. Use of the robust concept exploration method to facilitate the design of a family of products [J].Simultaneous Engineering, 1999, 12(11):247-178.
[12] Nayak R U,Chen W.Simpson T W. A variation-based method for product family design [J].Engineering Optimization, 2002, 34(1):65-81.
[13] Messac A. Martinez M P. Simpson T W .Introduction of a product family penalty function using physical programming [J]. ASME Journal of Mechanical Design, 2002, 124(2):164-172.
[14] Du Gang,Zhou,Haijing,Wang,Xikui.Spectrum research and application of aerospace products [J]. Quality and Reliability, 2011, (3):4-7.
[15] Sun Shaolin, Ma Zhiqiang, Tang Wei. Research on Gray-level Image Binarization Algorithms [J].Value Engineering, 2010, 29(5)):142-143.
[16] Tian Junqing, Xu Rongqing, Li Yaling, Yao Xiaoyu. An improved binarazation method for the fingerprint image [J].Microcomputer and Its Applications, 2010, 29(18):52-55.
[17] Qi Lina, Zhang Bo, Wang Zhankai. Application of the OTSU Method in Image Processing [J].Radio Engineering of China, 2006, 36(7):25-26.
[18] Chen Baishen. A New Algorithm for Binary Connected Components Labeling [J].Computer Engineering and Applications, 2006, 42(25):46-47.
[19] Ge Yuan, Guo Xingwei, Wang Lingquan. The Application of Fourier Descriptions to the Recognition of Alphabet Gesture. Computer Engineering and Applications, 2005, 22(6):12-13.
[20] Danielle Nuzillard, Cosmin Lazar. Partitional Clustering Techniques for Multi-Spectral Image Segmentation. Journal of Computers, 2007, 10 (2): 1-8.

[21] Shaoping Xu, Chunquan Li, Shunliang Jiang, Xiaoping Liu. Similarity measures for content-based image retrieval based on intuitionistic fuzzy set theory. Journal of Computers, 2012, 7(7):1733-1742.
[22] Jian Wu, Zhiming Cui, Pengpeng Zhao, Jianming Chen. Blocking Contourlet Transform:An Improvement of Contourlet Transformand Its Application to Image Retrieval. Journal of Computers, 2011, 6 (6):1168-1174.

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