Journal of Machine Engineering, Vol. 11, No. 3, 2011

culture of manufacturing,
passenger car design evaluation,
quantitative representation

Shin'ichi WARISAWA[1]

STUDY ON EUROPEAN MARKET-ORIENTED PASSENGER CAR DESIGN BASED ON QUANTITATIVE REPRESENTATION OF SHAPE CHARACTERISTICS

Due to the poor evaluation of the design of Japanese cars in the European market, this study proposes an evaluation to improve the rating of Japanese cars by Europeans. First, the concept of passenger car design evaluation is defined. Based on this definition, the appearance of a front image of a passenger car is decomposed into primitive components, and each component is analyzed in terms of shape, size, and position information. The shape information can be evaluated by two quantitative methods: Fourier series expression and aspect ratio calculation. To validate the evaluation method, five Volkswagen, four Peugeot, and three Toyota cars are sampled. The analysis indicates obvious differences in the headlights and radiator grille. Furthermore, a design modification method is proposed. Because design differences between European and Japanese cars are quantitatively evaluated, identifying necessary modifications should be easy. As a trial, one Toyota car design is modified by changing the features of the radiator grille and headlights to more closely resemble the characteristic shape of European cars. Then to validate the design modification, a design image investigation is conducted with the cooperation of 39 German citizens. This investigation demonstrates the design evaluation is effectively improved by altering the design of the headlights and radiator grille.

1. INTRODUCTION

Recently many companies have expanded into the international market. Hence, manufacturing enterprises should reinforce product marketability in both global and domestic markets. Globalization implies the necessity of localization in their activities; in addition to global appeal, a product must also meet culture- and region-specific designs and technologies. Therefore, global enterprises must research and develop their products in consideration with localization.

Herein the focus is on Japanese passenger cars and their marketability in Europe. Product development for Japanese car manufacturers centers on high quality products. Consequently, numerous European companies praise the quality of Japanese cars, but European consumers are not as knowledgeable about Japanese automobile companies. Even if Europeans can identify a Japanese automobile manufacturer by name, they do not know what Japanese cars are available in the European market. Toyota, a Japanese car manufacturer,

[1] The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656 Japan

is known as a global enterprise with the largest market share in Japan and the world. However, Toyota's European share was less than 6.0% in 2006 [1]. This low market share is attributed to the lack of acknowledgement among European citizens and the peculiarity of the European market. European consumers tend to purchase automobiles manufactured in their own country. For example, in Germany and France, domestic car manufacturers occupy over half the domestic market share, and the principal car manufacturer has 20 to 30 percent this share. To increase the Japanese car market share in Europe, brand recognition, knowledge, and impression of Japanese products should be improved. Two factors are related to a better impression: quality and design. The quality of Japanese cars is comparatively high and admired by European. Hence, design improvement is an urgent subject. According to the preliminary investigation, Japanese and European cars have remarkable design differences, which are major reasons for the low evaluation of Japanese cars.

Herein the design evaluation of passenger cars is discussed. Due to ambiguity in the design evaluation [2,3,4], this paper proposes a quantitative design evaluation method. The proposed method enables car designs to be modified for better marketability. Additionally, an actual Japanese car design is modified to improve its marketability in Europe, and a web-based questionnaire is conducted to validate the European-oriented modified design.

2. DESIGN EVALUATION OF A PASSENGER CAR

Passenger car design evaluation is generally to assess both product design and product image. Product design includes appearance, shape, function, and performance, while product image includes brand image and impression formed by advertisements, including TV commercials. Although all of these issues have been reported to influence product design evaluation, herein the appearance and shape of passenger cars are emphasized. Specifically, the areas of appearance are defined.

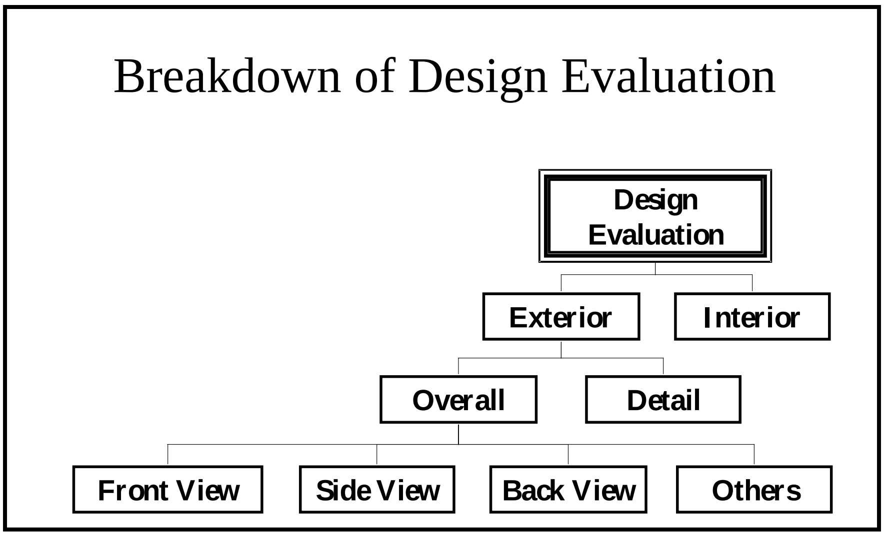


Fig. 1. Breakdown of design evaluation for a passenger car

Figure 1 shows a hierarchical breakdown of a passenger car for design evaluation. The product design evaluation is divided by interior and exterior features, which are evaluated by specific details and overall design. For instance, a so-called “Volkswagen-like car design” or “Toyota-like car design” is based on the impression of the overall appearance, while a detail evaluation is based on a specific detail like the headlights.

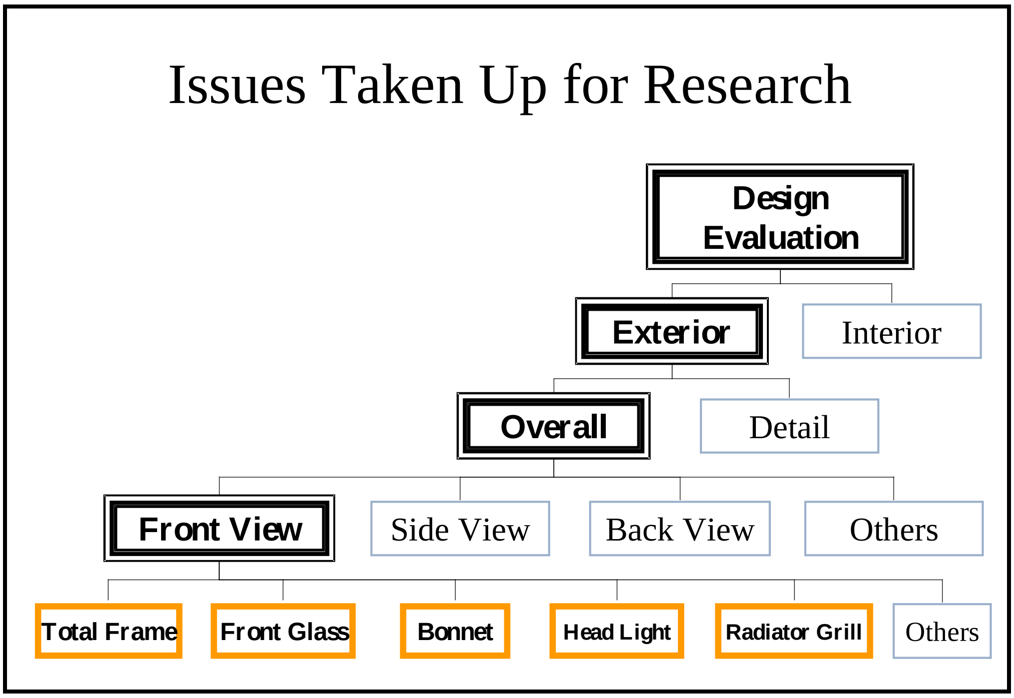


Fig. 2. Object components for a passenger car design evaluation

This paper addresses factors surrounded by the black bold line in Fig. 2. The analysis indicates European and Japanese passenger cars have common components such as a total silhouette, windshield, bonnet, headlights, and radiator grille. However, front images of those components differ due to their shape. Qualitative observations suggest that the poor design evaluation of Japanese passenger cars in Europe is due to differences in the shape characteristics of these common components. Accordingly, an evaluation method to rationally quantify these differences is crucial.

3. QUANTITATIVE SHAPE CHARACTERISTIC EVALUATION METHOD

As previously mentioned, shape differences should be quantitatively evaluated. Furthermore, how to improve a Japanese car design by comparison results is necessary. This paper defines the shape characteristic of each component by “shape information (round, square, etc.)”, “size information”, and “position information” (Fig. 3). Below quantitative representation of this information is explained in detail.

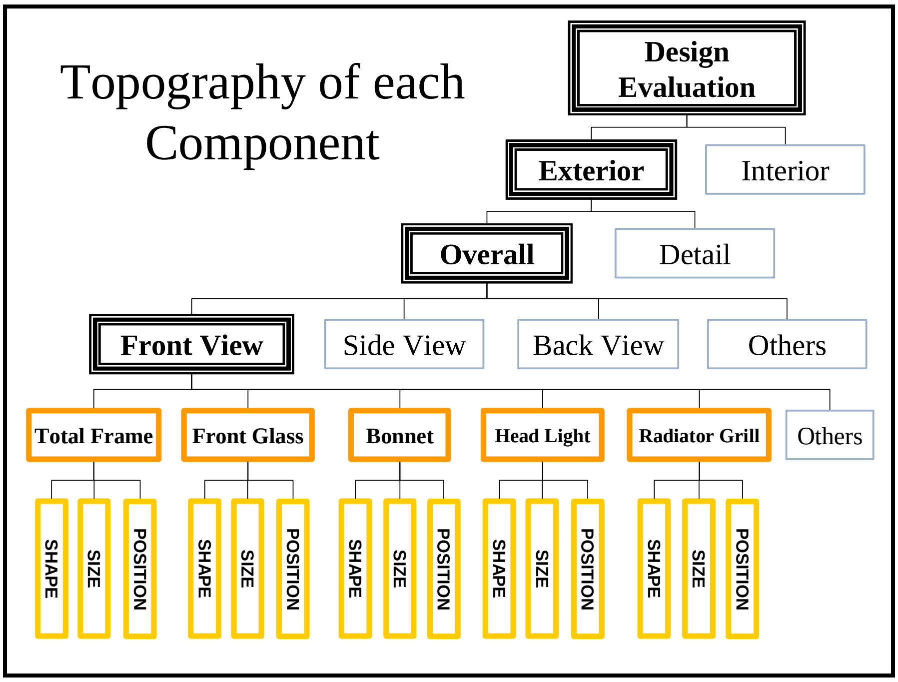


Fig. 3. Topography of each component

SHAPE INFORMATION

"Shape information" can be more than square, oval, or round. To evaluate shape information quantitatively, the following steps are necessary:

1. Prepare an image of an object passenger car.
2. Extract an outline of the object part.
3. Represent the outline by a quantitative expression.

Although numerous extraction methods have been proposed to derive an outline for step (2), this paper explains two different methods.

FOURIER SERIES EXPRESSION

To determine the level of unevenness of an outline and its direction, a Fourier series expression is applied. In the field of geometric morphometrics based on outline data, an elliptic Fourier analysis is generally applied to classify creatures by their shape. In this study, the author applies elliptic Fourier analysis, and proposes a method to determine the level of the unevenness of the shape as well as the direction of the unevenness.

Initially the author assumes a polar coordinate system, in which each point on an outline is defined by a distance r from the pole and an angle θ from the polar axis. The pole is defined as the center of the gravity of the outline, and the polar is defined as a ray from the pole in a fixed direction. An arbitrary periodic function can be represented by sine and cosine functions. In this way, the outline can be quantitatively expressed according to the following equation (Fig. 5).

$$r = f(\theta) = \frac{1}{2}a_0 + \sum_{n=1}^{\infty} a_n \cos\frac{2n\pi}{T}\theta + \sum_{n=1}^{\infty} b_n \sin\frac{2n\pi}{T}\theta \tag{1}$$

Where: $T = 2\pi$, and (a_n, b_n) are the so-called Fourier coefficients, which are expressed as

$$a_n = \frac{2}{T}\int_0^T f(\theta)\cos\frac{2n\pi}{T}\theta\,\mathrm{d}\theta \quad (n = 0, 1, 2, \dots) \tag{2}$$

$$b_n = \frac{2}{T}\int_0^T f(\theta)\sin\frac{2n\pi}{T}\theta\,\mathrm{d}\theta \quad (n = 1, 2, \dots) \tag{3}$$

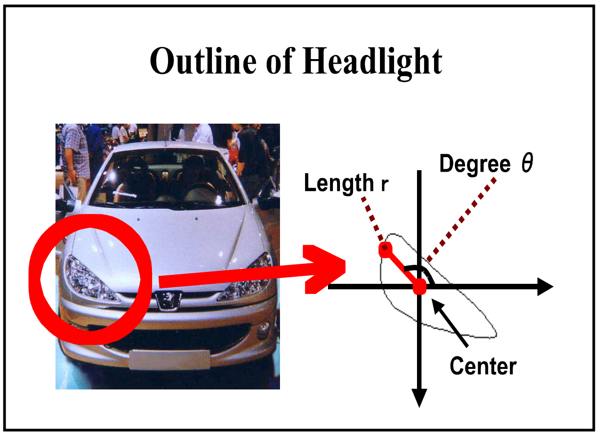


Fig. 4. Outline of a headlight

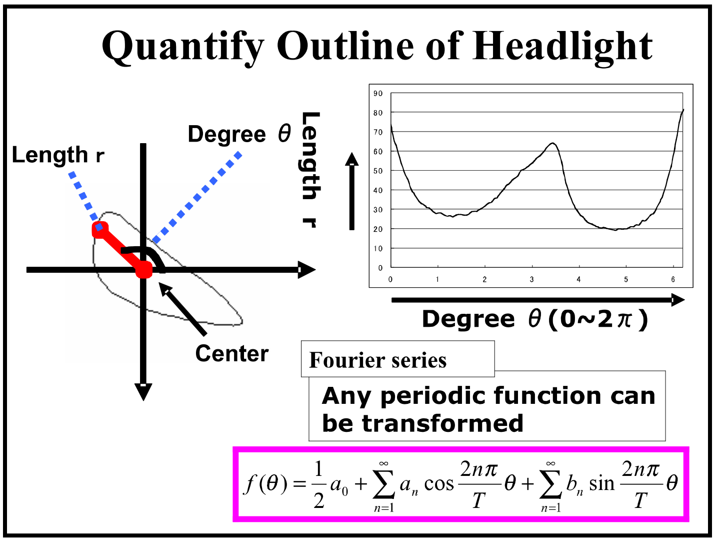


Fig. 5. Quantification by Fourier series transformation

Analyzing the coefficient of each term in the equation can identify shape information. When only the coefficient of $n = 0$, a_n has a non-zero value, Eq. (1) is transformed into

$$r = f(\theta) = \frac{1}{2}a_0 \tag{4}$$

The defined length r assumes a positive constant value for arbitrary θ. It explains that the shape of the outline is a circle.

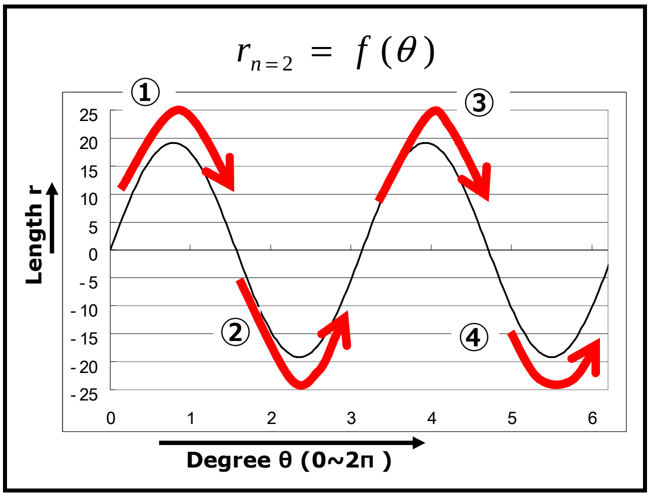


Fig. 6. $r|_{n=2} = f(\theta)$

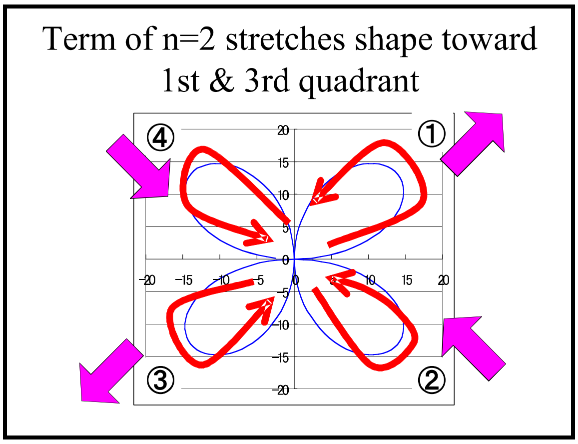


Fig. 7. Shape of the outline for $r|_{n=2} = f(\theta) = a_2 \cos\frac{4\pi}{T}\theta + b_2 \sin\frac{4\pi}{T}\theta$

If the coefficients of $(a_n, b_n)\ (n \neq 0)$ have non-zero values, and the defined length r takes a positive or negative value, depending on the value of θ. In other words, the defined length r changes from positive and negative as θ changes. Therefore, such a change of the defined length r represents the unevenness of the shape. The coefficients of terms (a_n, b_n) determine the direction of the unevenness.
For example, consider the case of $n = 2$. Eq. (1) is transformed as

$$r = f(\theta) = a_2 \cos\frac{4\pi}{T}\theta + b_2 \sin\frac{4\pi}{T}\theta \tag{5}$$

Furthermore, Eq. (5) can be transformed as

$$r = f(\theta) = \sqrt{a_2^2 + b_2^2}\sin(\theta + \phi),\ \phi = \tan^{-1}\frac{a_2}{b_2} \tag{6}$$

Figure 6 shows $f(\theta)$ when $\phi = 2n\pi$, while Fig. 7 shows an outline of the shape. Eq. (6) extends its shape in the first and third quadrant directions, but shrinks in the second and forth quadrant directions.

ASPECT RATIO

The method proposed in 3.1.1 has problems in providing shape characteristics of an extremely slim shape like a radiator grille. Observations of the shape characteristics of a radiator grille reveal that the differences among samples are the degree of length and narrowness of the radiator grille. Additionally, the inertial axis of the radiator grille is typically horizontal. Therefore, an aspect ratio is proposed to evaluate a radiator grille. The definition of the aspect ratio is expressed as

$$(Aspect\,ratio) = (Principal\,axis\,length)/(Average\,height) \tag{7}$$

The next issue is to calculate the principal axis length and average height. The author defines the principal axis length as the length for the line that links two points of the intersection with the principal inertial axis to the outline of the shape. The principal inertial axis is expressed as

$$y = x \tan \varphi_0 \tag{8}$$

The angle φ_0 gives a minimum value of the inertial moment of the shape. The inertial moment m_{φ_0} is expressed by the following equation

$$m_{\varphi_0} = \iint (x \sin \varphi_0 - y \cos \varphi_0)^2 f(x)\,\mathrm{d}x \tag{9}$$

where $f(x, y)$ is a function of the image information. $f(x, y)$ is 1 (0) inside (outside) the outline. The average height can be calculated as the average length of the shape in the direction vertical to the principal inertial axis.

SIZE INFORMATION

The size information of a shape can be easily represented by its area calculated by the following equation

$$S = \iint f(x, y)\,\mathrm{d}x\,\mathrm{d}y \tag{10}$$

POSITION INFORMATION

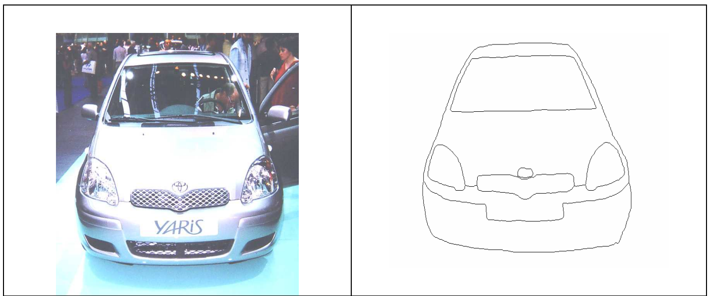
The position information of a shape is represented by the center of gravity for the shape. The center of gravity coordinates (x_g, y_g) are calculated by the following equations

$$x_g = \frac{\iint x f(x, y)\,\mathrm{d}x\,\mathrm{d}y}{S},\ y_g = \frac{\iint y f(x, y)\,\mathrm{d}x\,\mathrm{d}y}{S} \tag{11}$$

4. COMPARISON BETWEEN EUROPEAN AND JAPANESE PASSENGER CARS

4.1. PASSENGER CAR DESIGN SAMPLES

Three Toyota models, which are selected to represent Japanese cars, are compared to five Volkswagen models and four Peugeot models, which represent highly rated European designs. A photograph of the front view of each sample is used to extract outline of each component (Fig. 8). The images are normalized by reducing or enlarging each image as necessary. Then shape, size, and position information of the primitive components in the front-view image are extracted using the methods proposed in Chapter 3. As mentioned in Chapter 2, the front view consists of the total frame, front glass, bonnet, headlights, and radiator grille. As they show marked differences, below the comparison results for the headlights and radiator grille are explained.



Yaris (left: pic right: outline)

Fig. 8. Example of a sample image and extracted outline

4.2. COMPARISION OF HEADLIGHTS

The comparison indicates that the shape characteristics of a headlight for the 12 models have distinct differences between the European and Japanese models. Furthermore, each company has different position information for a headlight. Because the latter difference is by company, and not by region, the former result is further examined.

As for the shape information, Fourier series analysis is applied to the outline of the headlights. Figure 9 shows the frequency spectra from the results. Consequently, the shape information for European and Japanese cars have an assumed frequency value of $n = 0$ and $n = 2$, respectively. The spectral values of $n = 0$ and $n = 2$ quantitatively show a difference between European and Japanese cars in the oblate shape rate and direction of the oblate shape. First, each headlight is normalized to a circle with a radius of 100 pixels by referring to the spectrum of $n = 0$. Then the oblate shape rate represents how much the circle is transformed by the spectrum of the term of $n = 2$ in Fourier series expression. The direction of the oblate shape is calculated by Eq. (6).

Figure 10 shows the oblate shape ratio and its direction for all samples. The results indicate each company has a strong characteristic for the headlight shape, and the oblate shape ratio for Japanese cars is very low compared to European cars.

4.3. COMPARISON OF RADIATOR GRILLES

The shape information of the radiator grilles is analyzed by calculating their aspect ratios. Figure 11 shows the results of the aspect ratios for the 12 passenger car samples. Peugeot cars have much larger aspect ratio than Toyota and Volkswagen cars. The small variance in the aspect ratio within each car manufacturer means the aspect ratio of radiator grills expresses a characteristic of the company.

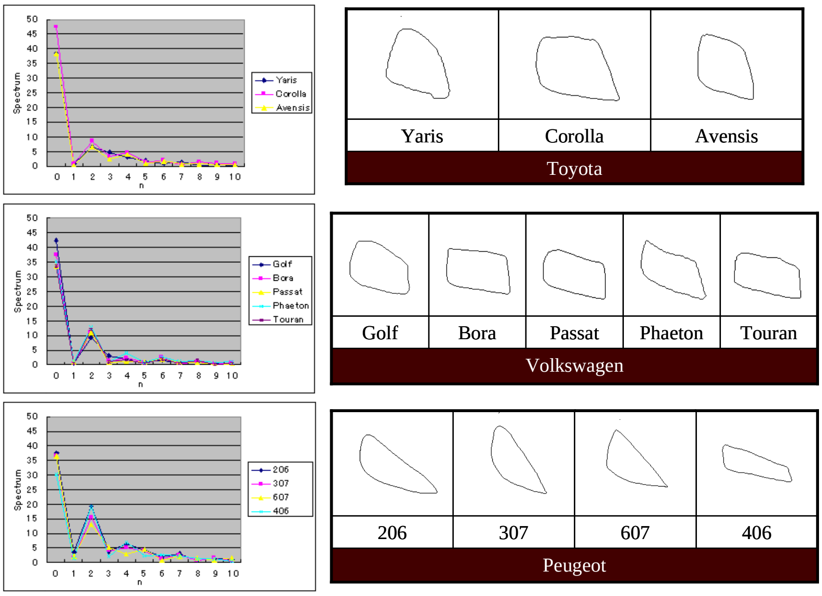


Fig. 9. Shape analysis of headlights

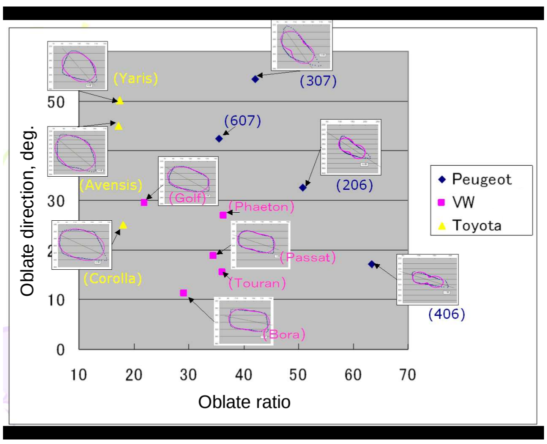


Fig. 10. Feature analysis of headlights

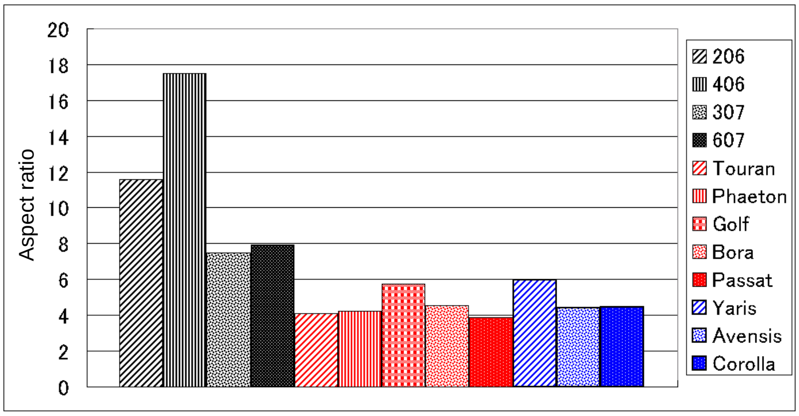


Fig. 11. Aspect ratios of radiator grilles

The analysis results of the size information and position information of the radiator grilles do not show a specific difference between European and Japanese. Only the Peugeot models 206 and 406 have a much smaller size and lower position than other models.

5. EUROPEAN MARKET-ORIENTED PASSENGER CAR DESIGN

5.1. DESIGN CHARACTERISTICS OF A EUROPEAN MARKET-ORIENTED PASSENGER CAR

The results from Chapter 3 demonstrate that the shape information for the headlights differs between European and Japanese cars. Therefore, design evaluation of the Japanese passenger car in Europe may be improved by applying the headlight characteristics of European cars to Japanese cars. Furthermore, the design characteristic of Peugeot car models, which have the highest design evaluation in Europe, should be emphasized. Specifically, the design characteristic of the radiator grille of Peugeot cars exhibits different features. Thus, the design of the radiator grille should be considered to improve the evaluation of Japanese passenger car.

5.2. DESIGN MODIFICATION OF JAPANESE PASSENGER CAR

5.2.1. HEADLIGHTS

The shape characteristic of a headlight is expressed by the oblate rate and oblate direction. The procedure to modify headlight design involves changing the coefficients (a_2, b_2) of the term of $n = 2$ in Eq. (1). Changing the coefficients alters the oblate rate and oblate direction. Based on the comparison results, the coefficients (a_2, b_2) are changed to the values of Peugeot 206.

5.2.2. RADIATOR GRILLE

The shape characteristic of the radiator grille is expressed by the aspect ratio. Although two factors influence the aspect ratio, e.g. principal inertial axis length and height, only the height is changed herein mainly due to the length limitation in the principal inertial axis direction for decrease in the aspect ratio.

5.2.3. DESIGN MODIFICATION RESULT

The design modification is applied to Toyota Yaris shown with reference to the design characteristics of Peugeot 206 (Figs. 12 and 13). Figure 14 depicts the three design

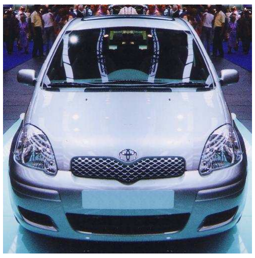


Fig. 12. Base design (Yaris)

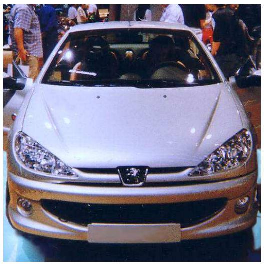
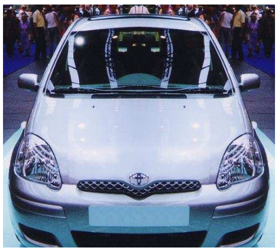
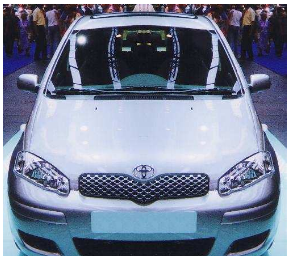


Fig. 13. Targeted design (206)



(a) Radiator grille modification



(b) Headlight modification

(c) Radiator grille and headlight modification

Fig. 14. European-based design modification

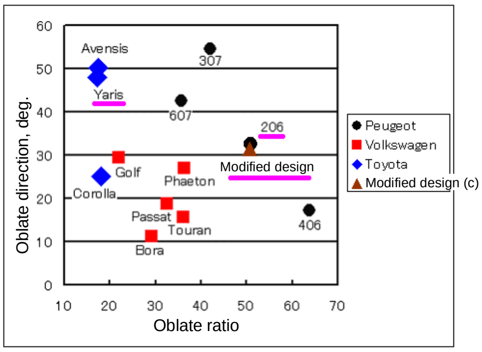


Fig. 15. Oblate ratio and direction analysis of the modified design

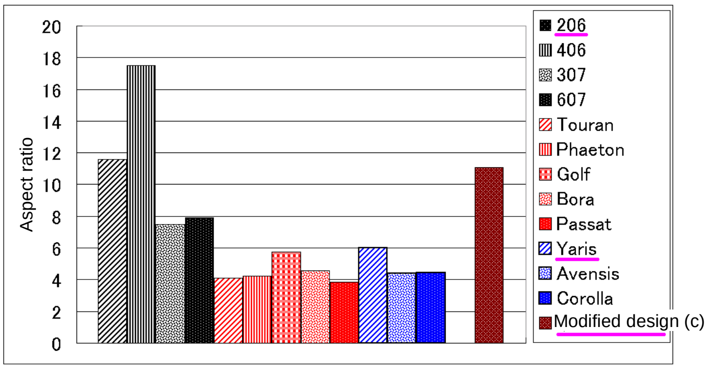


Fig. 16. Aspect ratio analysis of the modified design

modifications: (a) radiator grille, (b) headlights, and (c) both grille and headlights. The design analysis in terms of the oblate rate, direction, and aspect ratio for the modification models is depicted in Figs. 15 and 16. Design characteristic similarities can be acknowledged qualitatively and quantitatively.

6. DESIGN EVALUATION EXPERIMENT

6.1. EXPERIMENTAL METHOD

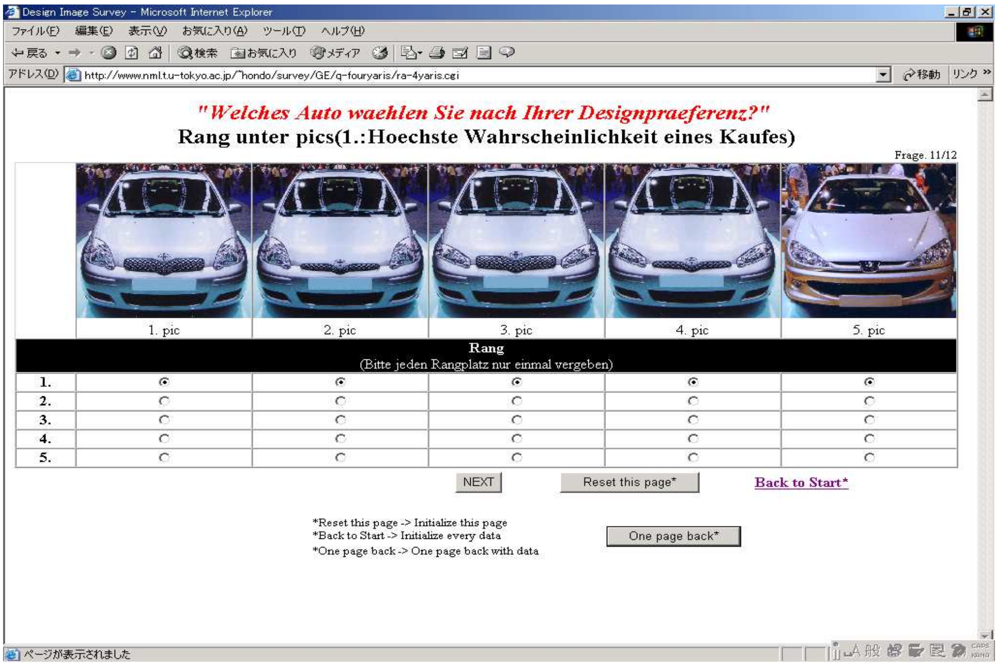
The modified designs, which consider the preferences of the European citizens, are expected to be highly evaluated. To confirm this hypothesis, a web-based questionnaire study (Fig. 17) involving 39 German citizens was undertaken. The subjects were asked to rank five models: Toyota Yaris, Peugeot 206, and three modified design. Because the subjects noticed the modified designs were based on a Japanese car, it is speculated that the modified designs would be ranked lower than the Peugeot 206. Hence, the subjects were also asked to select any keywords relevant to each model from a list of 50 keywords. The keywords should elucidate changes due to the design modification, even if the modified design evaluation is not improved. Hua-Cheng Chang's group has employed a similar methodology on research about the attractiveness of a passenger car [4], and Tanoue's group applied this idea to the perception of vehicle's interior image [5].

6.2. EXPERIMENTAL RESULTS

Figure 18 shows the ranking results. The modified designs are evaluated higher than Toyota Yaris. Detailed analysis of the results suggests that headlight modification has a larger impact than modification of the radiator grille, while a combination of the two provides the most improvement.

The keywords for the Toyota Yaris and Peugeot 206 drastically differ, but this difference decreases between the most popular modified model and the Peugeot 206 (Table 1). The

a)



b)

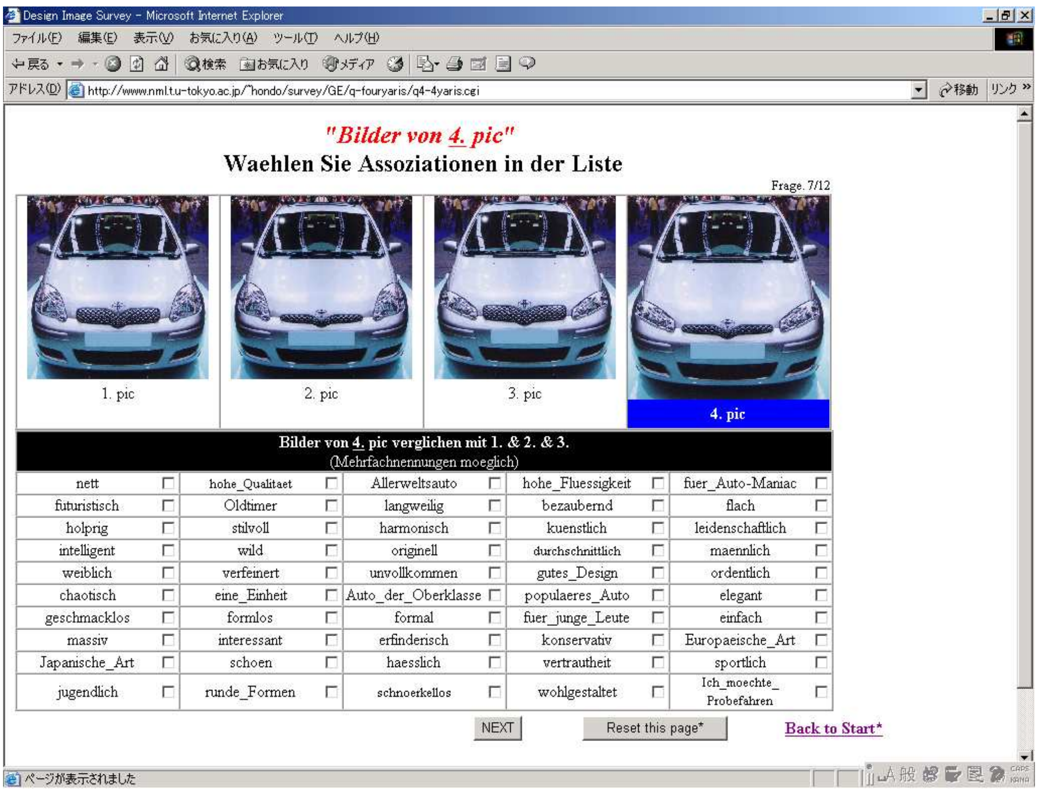


Fig. 17. Web-based questionnaire
a) ranking research b) image research

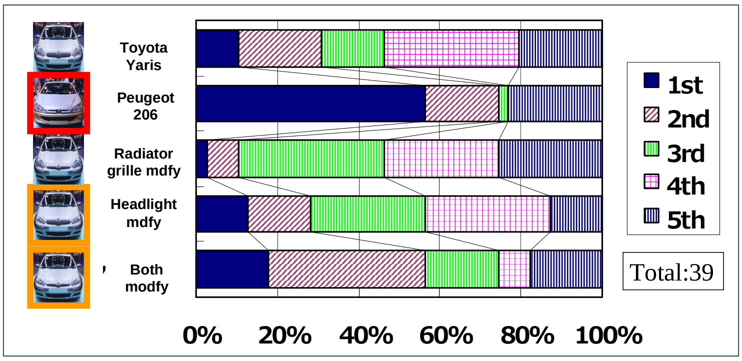


Fig. 18. Evaluation results

Table 1. Image keyword differences

Toyota Yaris (Japanese oriented image)	Headlight & radiator grille modified design	Peugeot 206 (European oriented image)
Cute Universal Uneven Feminine Japanese Rounded Plain	Japanese Plain Formal	Futuristic Sensitive Wild Sporty
7 words	3 words	5 words

image keywords for Toyota Yaris are thought to be associated with Japanese car images, while the image keywords for Peugeot 206 are believed to be associated with European car images. According to the hypothesis, the modified design decreases the image keywords associated with Japanese car image, although none of the keywords are associated with European car images. Thus, it is concluded that modified design is ranked higher because it is not as closely associated with the Japanese car image.

7. CONCLUSIONS

This research aims to improve the design evaluation of Japanese passenger cars by European citizens. Although various factors affect design evaluation, this paper focuses on the appearance and shape of a passenger car. Because a passenger car is composed of many parts, they are broken down into primitive components according to the passenger car structure. Analysis of the primitive components indicates that size, shape, and positional information can be evaluated by the primitive components. Moreover, this research proposes a design modification for the European market. To clarify the differences between European and Japanese passenger car designs, a quantitative method to evaluate the shape, size and positional information is proposed, and subsequently applied to compare Volkswagen, Peugeot and Toyota cars. Their designs differ in terms of headlights and radiator grille. Furthermore, a design modification based on design analysis is undertaken, and a web-based questionnaire about the modified designs confirms that the design evaluation improved.

Specific conclusions are summarized as follows.

(1) A Fourier series expression is utilized to represent the unevenness and direction of a shape outline. Plotting the results of the Fourier series in the frequency domain can visual the differences in the shape characteristics. The coefficient for each term of the Fourier series expression represents different shape information.

(2) An aspect ratio calculation is also utilized to represent the shape outline. Because a target outline is not always rectangular, the aspect ratio is defined by the principal inertial axis length and average height.

(3) Comparison between European and Japanese passenger cars indicates the headlight shape information clearly differs. As for the radiator grille, Peugeot cars have a distinguished characteristic in their aspect ratio.

(4) A design modification is applied to the Toyota Yaris in terms of the headlights and radiator grille. A web-based questionnaire investigation of the design evaluation with the cooperation of 39 German citizens indicates the modifications improved the design evaluation.

(5) This investigation demonstrates the importance of headlight design in a passenger car to enhance European marketability.

ACKNOWLEDGEMENT

The research was conducted by Mr. Satoshi Hondo, one of the author's students. The author received advice from Prof. Mamoru Mitsuishi. Drs. Klaus Ruth and Fozzy Moritz mobilized the subjects for the questionnaire investigation. The author expresses sincere appreciation for the cooperation, advice, and support.

REFERENCES

[1] European Automobile Manufacturers Association, "New Motor Vehicle Registrations Annually, Historical series: 1990-2007," (http://www.acea.be/statistics) 2007.

[2] WARISAWA S., MURATA S., ITO Y.., YEE S. K., LAI G. J., 1997, An International Comparative Study on Package Design of Lid of Instant Noodles –Marketability Estimation for Racial-Oriented Products, JSME CENTENNIAL GRAND CONGRESS International Conference on Manufacturing Milestones toward the 21st Century, 235-240,

[3] WARISAWA S., WILLINGS R. M.., ITO Y., 2001, Quantitative Visualization and Evaluation of Thought Processes Based on Importance Factors Connectivity Map in Checking a Detail Drawing, INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN ICED 01 GLASGO.

[4] CHANG. H.Ch., LAI H.H., Yu-Ming CHANG., 2007, A measurement scale for evaluating the attractiveness of a passenger car form aimed at young consumers, International Journal of Industrial Ergonomics, 37, 21-30.

[5] TANOUE Ch., ISHIZAKA K,. NAGAMACHI M., 1997. Kansei engineering: A study on perception of vehicle interior image," International Journal of Industrial Ergonomics, 19, 115-128.