STYLE ANALYSIS METHODOLOGY: IDENTIFYING
THE CAR BRAND DESIGN TRENDS THROUGH
HIERARCHICAL CLUSTERING

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Abstract. This paper aims to identify car design trends within various
automobile manufacturers by investigating two objectives: first, finding
similarities between car styles among different car brands from
various automobile manufacturers to specify unique car designs which
lead the trend; second, identifying the consistency of the brand design
characteristics through hierarchical clustering. To do that, Fourier de-
composition was used to quantify the car design similarities between
120 cars from 23 different brands. The calculated similarity index is
then compared with network centrality measures to identify the clus-
tering of the car brands. The quantified style data then can be applied
to accurately predict the design trend. Thus this study can contribute
to identify car style trends for strategic design decisions.

Keywords. Style analysis; design trend; brand cluster; brand identity.

1. Introduction

As the automobile industry shifts into the maturing state through the tech-
nical and manufacturing improvements, the design aspect has become more
significant than the technical aspect such as the engine (Gu, 2005). The sig-
nificance of car designs is reflected by the fact that 70\% of the purchase in-
tent of a car is related to car designs (Cheutet, 2007). This can be explained
by the close relationships between styles of car designs—also known as the
brand identity—and the specific target market. Brand identity can be de-
scribed in two main categories: explicit and implicit (Karjalainen. 2007;
Ranawat et al.. 2009). Explicit includes shape, texture, colour and material
while implicit concentrates more on experiential elements such as smell,
sound and comfort. It is the mixture of the explicit and implicit elements that creates brand identity.

When finding similarities between car styles among different car brands from various automobile manufacturers, it is important to analyse the explicit aspect of brand identity: the exterior physical shapes. The exterior shapes of the cars share similar structural parts but it is the small variation of these structural part shapes that create the unique characteristics of the car for brand identity. As Orsborn et al (2006) said, "many of the characteristics of vehicles occur in multiple classes of vehicles and it is the parametric range of these characteristics that determine within which class the vehicle falls." There are many different ways to manipulate the designs of cars by adding variations in the structural parts but there are certain design tendencies for each automobile manufactures that establish unique style of their own.

Automobile manufacturers have their own unique brand identities. Brand identity is strongly related to the target market of the manufacturer through brand design strategies. Chris Bangle (Menandmotors, 2002) explained that the automobile companies have different brand design strategies: the single driven strategy and the market driven strategy. The single driven strategy focuses on a singular value system that creates a series of recognizably similar product designs within the singular shape framework. Thus, single driven strategy consistently attracts the specific group of customers who prefer the certain design market segments. Some of the examples of the automobile companies that use single driven strategy are Audi, BMW, and Mercedes-Benz. Unlike the single driven strategy, the market driven strategy concentrates on creating different value system. In other words, the main goal of the market driven strategy is to create various product designs to fulfil multiple market customers’ needs. Examples of the automobile manufacturer that use market driven strategy are Hyundai, Honda, and Toyota. Although brand design strategies provide unique brand identities, even within each of the brand design strategies, there are various clustering of the car brands due to the manufacturer’s brand values.

The car brands can be clustered in accordance with the brand values and then be visualized onto an opportunity map to facilitate the strategic decision-making process by providing a better insight into the market positioning of a company (Zhao et al, 2005). Similarly, the clustering of the car designs can be visualized onto an opportunity map for strategic design decisions. In order to achieve this, the car designs from various automobile manufacturers and car brands need to be analysed and clustered. We use the Fourier decomposition to measure the similarity between each of the car designs, and a hierarchical clustering method to measure the grouping tendencies of the 23 different brand identities. For this purpose, the following tasks are conducted
in this paper: first, photographs of the car designs were collected; second, similarity index was generated through the Fourier decomposition; third, hierarchical clustering was used to group the car models.

2. Related Studies

McCormack et al (2004) stated that the style of the car is perceived by recognizing repeatedly used forms. In other words, by analysing the assemblies of forms, it is possible to evaluate the style of the car. There are two major methods for analysing the style in the field of computational design based on sharing the same idea of investigating on the repeatedly recognizable parts of the design: first, Chan’s style measuring method; second, shape grammar.

Chan’s style measuring method (Chan, 2000) for identifying the styles of Prairie Styled architectures is one of the taxonomic style evaluations. Chan argued that by investigating repetitious forms, features, and syntax, the style can be identified. Therefore by analysing the form composition the style can be analysed through the set comparison analysis. For instance, Prairie House Style included, low hip roof, band of casement windows, continuous bands of sill, extended terraces with low parapet and coping, water table, corner clocks, planting urns, massive brick chimney, continuous wall between sill and water table, overhanging eaves, and symmetric side façade. While the Chan’s style measuring method works in a taxonomic fashion and provides numeric values on similarity, it does not provide detailed information on how similar the styles are—similarity index.

Another style analysis method is a shape grammar, which is a methodology for analysing and creating shapes. The advantage of it is that it is represented graphically (Li, 2011). The graphical representation allows the analysis and the synthesis of the style to be more effective than other taxonomic analysis methods. In addition, it helps to understand the process of how initial shape is transformed into final design through applying transformation rules. While shape grammar allows the analysis and the synthesis of the style, even three-dimensionally (Orsborn et al., 2006), similar to Chan’s style measuring method, it does not provide the similarity index.

The classical style analysis methods, Chan’s style method and shape grammar are determined to be inadequate for this research, which requires how similar the shapes are. Thus, in order to analyse the similarity of the form, another method was considered. The Fourier decomposition approach represents the repetitive periodic functions. The Fourier decomposition on closed curves is expressed by a complex function (Cluzel et al, 2012). The frequent characteristics alleviate the inaccurate curve representations and improve the consistency of the curve. Fourier decomposition will be used to
identify the brand shapes for the following reasons: 1) Fourier decomposition can generate similarity index in any orientations therefore reducing the data gathering process time; 2) Fourier decomposition is adaptable to the genetic algorithms. Since the Fourier decomposition only works for the closed curvatures, Cluzel et al (2012) evaluated the car silhouettes from the sides only. As one of the small steps toward providing strategic design decision making method, the curve similarity analysis method from Cluzel et al (2012) using the just the car silhouettes is incorporated with the hierarchical clustering for grouping the car designs.

3. Methods

For this paper, we used two methodologies for bi-level analysis. First level is the similarity index generation using the Fourier decomposition method. We use a total of 120 car designs, and each car design has one side view silhouette, a simple closed curve represented by a collection of points. Second is the network hierarchical clustering for grouping the car models.

The Fourier decomposition was used by Cluzel et al (2012) for synthesizing car designs with genetic algorithm. Formula for the complex Fourier coefficient used in Cluzel et al (2012) can be written as follows (1):

$$ a_m = \sum_{k=0}^{N} \frac{r_{k+1} - r_k}{2} \cdot z_{k+1} \exp(-2\pi imr_{k+1}) + z_k \exp(-2\pi imr_k) $$

Where $z_k$ is the points representing the curves, and the numeric approximation is generated by segmenting the curves in the $N$. $r_k$ is the distance between the point $z_k$ to $z_{k+1}$. The similarity of the two curves can be generated as follows (2) (Cluzel et al, 2012):

$$ \text{SimInd}(k, l) = \frac{100}{1 + d(k, l)} \% = \frac{100}{1 + \sum_{m=1}^{10} \alpha(m) \|\theta_m - \theta'_m\|^2} $$

The distance between two different curves, $\theta_m$ and $\theta'_m$ are measured, where $m$ is the number of the point. The similarity index is generated from 0 to 100% where the higher similarity index value means more similar the curves are.

As for the second level analysis of the network hierarchical clustering for grouping the car models, the findings from the first level analysis – which is the similarity index – can be incorporated as distance values for grouping the similar designs. Steinbach et al (2000) said that the hierarchical clustering separates series of partitioned groups of the data from bottom to top. The more similar the data is, the more clustered it is, thus having lower tree height. The branching point is shown as the similarity of the data decreases. As a result, graphical representation of the tree, also known as cluster den-
drogram, can be generated by the hierarchical clustering algorithm (Figure 1). Cluster dendrogram was used for network clustering with distance matrix generated with the similarity index.

![Figure 1. Cluster Dendrogram example (taken from Steinbach et al, 2000)](image)

4. Implementation and Result

The car design features were collected from the images from the professional online automobile photograph database. The body silhouette of the car design is obtained from the photographs and stored as closed curves. Table 1 shows the list of the brands and car models that were evaluated for this research and the body silhouettes of each of the car models – total of 120 models – were used for style analysis.

<table>
<thead>
<tr>
<th>Brand</th>
<th>Model Names</th>
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Using the 120 model body silhouettes from the side, a total of 14,400 values of the similarity index using the Fourier decomposition are created by the adjacency matrix. As shown in Figure 2, the similarity value of near 10% has the highest count, meaning that the large volumes of the car models are the uniquely designed cars.

The similarity values were measured by the distances between points from car model 1 and car model 2 in periodic function. Therefore, the more similar the shapes of the curves are, the higher the value becomes. In order to confirm the similarity index value between different car models, the relationship between the visual shape of the car body silhouette and the similarity index value of the car models, four car models—Saab 9-5 2009, Saab 9-5 2006, Kia Optima 2004, and Dodge Avenger 2009—were randomly selected for sample analysis. As illustrated in Figure 3, the higher the similarity index value, the more similar the car shapes are. Saab 9-5 2009 and Saab 9-5 2006 have a similarity index value of 79.77%; Kia Optima 2004 and Dodge Avenger 2009 —2.05%; Saab 9-5 2009 and Kia Optima 2004 —9.97%; Saab 9-5 2006 and Kia Optima 2004 —11.00%; Saab 9-5 2009 and Dodge Avenger 2009 —1.90%; and Saab 9-5 2006 and Dodge Avenger 2009 —1.90%.
From the above similarity index values, we can cluster the automobile models with high similarity index and exclude models from the cluster with low similarity index. For instance, Saab 9-5 2009 and Saab Saab 9-5 2006 can be grouped as a cluster while Dodge Avenger 2009 is a part of a different cluster. Kia Optima 2004 can be considered as an independent cluster from Dodge Avenger 2009. Kia Optima 2004 is closer to the Saab 9-5 2009 and Saab 9-5 2006 cluster than Dodge Avenger 2009. By visually confirming how similarity index values affect the clustering, the sample mechanism used above is applied to the hierarchical clustering of the 120 car models.

The result of the cluster dendrogram is shown in the Figure 4 where lower the height, more similar the car silhouette shapes between two grouped car models are. For example, Mercedes Benz E-Class 2010 and 2013 grouped at near 5 height of the cluster dendrogram, are almost identical while the Honda Accord 2000, 2003, Chevrolet Malibu 2008, 2003, Mazda Mazda6 2003, 2011, Ford Fusion 2006, Buick Regal 2012 located on the upper left corner are the least identical. From the cluster dendrogram, it is easy to see four different clusters—one on the very right hand side, one on the right middle side, one on the left middle side, and one on the very left hand side. While the cluster on the very left hand side is composed of car models with unique designs with the exception of Mercedes Benz E-Class 2010 and 2013, the cluster on the right hand side is composed of car models with some commonalities in design.
A total of 80 clusters from 120 car models was grouped heuristically as shown in Figure 5. More than one third of the clusters (43 car models) consist of a single car model, which is equivalent to a cluster of size 1. This indicates that 43 car models have unique designs, while the remaining 77 car models are grouped under certain design languages according to their similarity.

In addition to the distribution of the 80 clusters, the 120 car models are represented in a cluster dendrogram, and the network of car design models is constructed based on the similarity values, which function as the weighted degree. The weighted degree of the network is summed up for each node...
(car model), therefore acting as a centrality measure. The car models that have the highest weighted degree value (darker nodes) are the models that have the most similar designs among all the 120 car designs (Figure 6). To evaluate the most common designs, the degrees of all the car models, and brand and production year was included. As a result, Lexus had rather common designs until the 2013 (year/weighted degree: 2001/1287.17; 2004/1525.25; 2008/1839.60; 2011/1815.21) when Lexus 2013—indicated in Figure 6—design become more unique in silhouette appearance (weighted degree = 1068.09). Lexus 2013 found to be the quite unique and are different to other car model designs are located in the right middle side of the cluster dendrogram with the highest heights.

Figure 6. Centrality network of the 120 car models
(120 cars are represented as nodes, darker nodes for higher weighted degrees).
5. Conclusions and Future Work

The style analysis conducted in this research has shown that there are tendencies of similar designs within the automobile industry independent of the year it was made and the car manufacturing industry it was designed from. In addition, it showed the transition of the Lexus’s periodic design changes and revealed the automobile industry’s design tendencies. In addition, methods used in this paper can contribute to identifying style trend transitions for strategic design decisions in the field of architecture, fashion, graphic design and other design related fields. In the future, we will extend our work to other important car design elements such as the grill, headlight and the bodyline, not just the body silhouette. For more accurate clustering methods, several extended researches are required. First, car design is composed of multiple design elements such as fender, grill, lights, doors and window. It is important to incorporate such design elements for more accurate clustering. Second, extended research is needed for the case when the multiple car design characteristics, which cannot be expressed as closed curves, incorporated for the style analysis. Finally, it is important to consider human perception to find the visual significance of the design element since each car design characteristics have different impact on viewer’s memory.

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