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Style synthesis and analysis of car designs for style quantification based on product appearance similarities

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ABSTRACT

Understanding how similar design appears is a key element to understanding companies' design strategies. However, it is difficult to evaluate companies' design strategies with conventional style measurement methods since they only taxonomically measure whether a specific characteristic is included in a specific style. This study numerically measured car design similarities to synthesize and analyze car brand styles, thereupon discovering the design trends among car brands for strategic design positioning. This paper aims to find methods for quantifying style differences and identifying unique design elements of car designs among 23 automobile manufacturers based on design similarities of a large quantity of car designs ($N = 119$). To achieve this goal, a hybrid style quantification methodology – a mixture of Fourier decomposition, eye tracker, and shape grammar – was created to evaluate similarities, visual significance, and combinations of 19 car design elements. Fourier decomposition was incorporated to find the quantifiable values of design similarities of car design elements. Visual significance analysis was also conducted for each car design element through eye tracker to measure the importance of certain design elements for weighting factors. Then, each combination of design elements was compared with car design elements of other cars for similarity calculations. Finally, car design alternatives were synthesized, and transitions of design positioning were analyzed based on the similarity values weighed by the visual significance results. Using the suggested methods, alternate designs can be synthesized while preserving brands' design styles, and design trends can be analyzed for strategic evaluation.

1. Introduction

Style is used strategically in various industries to communicate their brand identities to customers [1]. When it comes to car designs, car manufacturers strategically use styles of car designs to familiarize or differentiate themselves from their competitors depending on their strategies [1–3]. The importance of design in the car industry increased since it reached a mature stage, and visual recognition has become a strategic goal of car manufacturers for customer assessment of car brands [4]. Currently, companies strategically use design styles to satisfy their target markets. According to Hallam [5], there are two major design strategies: single-driven and market-driven. The single-driven strategy is used to attract target groups of customers who prefer certain design segments by creating recognizably similar product designs. The market-driven strategy is used to create manifold product designs to satisfy the needs of multiple market segmentations. According to Person et al. [1], companies strategically decide to style products similarly to or differently from existing products and competitors' products. Therefore, understanding how similar design appears is a key element to understanding companies' design strategies.

Creusen and Schoorman [6] argued that the product appearance similarities play a crucial role in increasing ergonomic, functional or symbolic value expectations of products. Despite the importance of design in strategic marketing, designers depend on their personal design experience when creating new design concepts focused on meeting market demands [7–11]. The absence of a methodology to quantifiably analyze designs makes it difficult to systematically evaluate and explain a design's uniqueness, its consistency, and any brand associations, especially for strategic design positioning. If the design serves to attract customers and maintain customer loyalties, how do designers navigate the uncertainty inherent in design decisions? According to style analysis literature, style can be measured by understanding the unique traits of design elements that represent the style sets [12–15]. The problem with

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the current style measurement methods is that they only measure whether a specific characteristic is included in a specific style. These methods do not measure how different the designs are. While there are inconsistencies in measuring methods of styles in the field of design, this measurement of design similarity has become critical for the car design industry in two ways: design synthesis and design analysis.

Design synthesis is important for designers to generate alternative designs while maintaining the original style to efficiently meet the engineering requirements [16]. For instance, it is the designers' job to generate design alternatives while fulfilling brand styles and manufacturing requirements since late styling changes increase the time and cost of production [17]. Designers expend effort into strategic styling decisions, including whether to make their designs similar to those of competitors for successive product generations [1]. It is critical to experiment with alternative designs while effectively choosing which design best fits products' strategies and satisfying engineering and manufacturability requirements.

Companies regard product design as a valuable asset to achieve a competitive advantage [18,19], and therefore design analysis can help to evaluate brand associations and determine the competitiveness of a brand. Companies with limited resources strategically imitate competitors' brands for brand association effects while companies with resources differentiate brands for more distinctive identity [20]. As imitators save design research investments while waiting for market reactions by analyzing customers' needs in relation to existing designs [21], it becomes more important to establish successful design strategies incorporating not only creation of innovative designs but also design surveillance on competitors in the market to evaluate brand associations. However, such a systematic approach incorporating design strategies for making managerial decisions has been limited by the absence of design similarity quantification methods. Through a hybrid style quantification methodology, companies can readily evaluate design similarities and also utilize the methodology to differentiate their design from others for managerial decisions.

To fulfill both synthesis and analysis with a style quantification methodology, this paper focuses on finding the similarity of car design elements among various car brands to investigate how different their designs are. A hybrid style quantification methodology was developed by associating a graphic style analysis method – shape grammar – with a numeric style analysis method – Fourier decomposition. In addition, an eye tracker was used to evaluate the visual significance of the design elements since some elements can be recognized more effectively than others if they appear more interesting than others. To accomplish these analyses, we have conducted multiple tasks: first, photographs of car designs were collected for style quantification; second, the collected photographs were processed with the hybrid style quantification method to derive similarity measurements; third, unique design elements of the car brands were identified; fourth, a visual significance analysis was conducted to create a design element hierarchy; and fifth, new car designs were synthesized based on the second and third tasks; lastly, the design trends of the car brands were analyzed.

2. Related work

2.1. Style analysis methods

Our studies on style analysis were conducted by evaluating brand identity because the visual consistencies of the car manufacturers vary depending on the car brands. Despite that brand identity is shaped by two types of factors – explicit and implicit, where explicit factors include various elements such as color, shape, and texture, and implicit factors include brand identity and experiential identity such as smell, sound, and comfort [9] – brand identity is strongly related to physical elements, which are semantically transformed from brand language domain characters [3,9,22]. Thus, brand identity is formed by repeatedly-used explicit design elements [9,14,23,24]. The styles of car manufacturers can be evaluated by analyzing the explicit features (physical appearance) of cars. Cheutet [25] showed that a car's profile could be expressed through a combination of ten lines; the car design elements are evaluated based on the stylistic curves as shown in Fig. 1.

According to literature reviews on style quantification methods, these methods can be categorized into two major types: taxonomic and numeric. Taxonomic methods, such as Design Feature Analysis, Chan's method, and Shape Grammar, have been widely utilized by design researchers in the field of industrial design and architecture [13–15,24]. Numeric methods, such as parameterized contour, wavelet, and Fourier decomposition, have been thoroughly researched by computer scientists to efficiently detect images. There have been attempts to apply numeric methods to quantify physical appearance of designs, but these attempts mainly focus on the numeric method's application for the generative algorithm [26,27]. Cluzel et al. [26] created a table of style quantification methods for their generative algorithm projects (Table 1) to discuss the pros and cons of the two different style evaluation methods. Further explanations of Table 1 will be discussed in the next section.

2.1.1. Taxonomic style evaluation method

There are several methods for quantifying the shape elements of a style, including Design Feature Analysis (DFA), Chen's style measuring method, and Shape Grammar. DFA is capable of evaluating repeated design elements though occurrence evaluation. DFA collects design elements of style heuristically. For instance, Karjalainen [28] measured the style of the Volvo sedan, and described its repetitive design elements as "soft nose and grille," "V-shaped bonnet," "Shoulder line," "Taillights," "Third Side Windows," and "Flowing Line." These descriptions are understandable when shown alongside images of the Volvo sedan, but other car brands share these design elements as well. For instance, Audi has "soft nose and grille," "V-shaped Bonnet," and "Shoulder-line." Some of the elements may be shared, but this is not the most accurate way to measure the shape. As Karjalainen [28] stated, the validity and reliability of DFA depends on the selection criteria of product features. In other words, DFA is not capable of consistently evaluating details of design elements.

Chan's style measuring method [12] for identifying the styles of Prairie Styled architectures is another choice for taxonomic style evaluation. Chan argued that style could be identified through repetitive forms, features, and syntax. Therefore, by analyzing form composition – the form of a set of prominent feature – the style can be analyzed through a set comparison analysis. Based on Chan [12], Prairie House Style included the following: a low hip roof, bands of casement windows, continuous bands of sill, extended terraces with low parapets and coping, a water table, corner clocks, planting urns, a massive brick chimney, a continuous wall between sill and water table, overhanging eaves, and a symmetrical side façade. Chan's style measuring method works in a taxonomic fashion but also provides numeric values on similarity. However, it does not provide detailed information on how the shapes of the forms are different.

Shape grammar is a methodology for analyzing and creating shapes. The advantage of shape grammar is its ability to represent its findings graphically [13]. It allows the analysis and the synthesis of the style to be presented more effectively than other taxonomic analysis methods. Shape Grammar helps to explain the process of how an initial design's shape can be transformed into