Advanced Engineering Informatics 29 (2015) 662–679

Contents lists available at ScienceDirect

Advanced Engineering Informatics

journal homepage: www.elsevier.com/locate/aei

A study that applies aesthetic theory and genetic algorithms to product form optimization

Chi-Hung Lo [a,*], Ya-Chuan Ko [b], Shih-Wen Hsiao [c]

[a] Department of Industrial Design, Tunghai University, No. 1727, Sec. 4, Taiwan Boulevard, Xitun District, Taichung 40704, Taiwan, ROC
[b] Department of Creative Product Design, Asia University, No. 500, Lioufeng Rd., Wufeng, Taichung 41354, Taiwan, ROC
[c] Department of Industrial Design, National Cheng Kung University, No. 1, University Rd., Tainan City 701, Taiwan, ROC

ARTICLE INFO

Article history:
Received 8 January 2014
Received in revised form 21 June 2015
Accepted 22 June 2015
Available online 9 July 2015

Keywords:
Aesthetic measure
Form optimization
Fuzzy theory
Genetic algorithm
Aesthetic product design
Product evaluations

ABSTRACT

In the past, designers developed new products by virtue of their own accumulation of aesthetic perception and experience. Because the information that designers could master was limited, it was difficult to develop quickly the capability of satisfying consumer-oriented markets. This limitation may consequently cause the enterprises unnecessary risks. Based on this, a set of aesthetic evaluations and an optimization system for form aesthetics are proposed in this study. Calculations of explicit equations were performed so as to assisting in measuring the aesthetic characteristics; next, a fuzzy judgment was invoked to calculate the perceptual aesthetic measures of a product style so as to establish the overall aesthetic standard for the product. Aesthetic measurement principles were combined with the genetic algorithm (GA) and applied to the optimization of the product's shape. All-in-one stereos were chosen to serve as the target products as a case study. Further form optimization was conducted on two of the stereos and the questionnaire survey indicated that their aesthetic measures increased after the optimization. The errors that resulted from the equations for aesthetic measurements and judgments were also reduced accordingly. The precision and feasibility of the aesthetic theory that was constructed in this study were assessed, tested, and verified.

1. Introduction

The value added to each product is continuously enhanced under the globalization of competition. Therefore, an innovative design of products is the key factor for enterprises to acquire a competitive edge. In the past, designers developed new products by virtue of self-accumulation of aesthetic perception and experience. With this approach, it was difficult to secure the capability of satisfying the consumer-oriented markets. And it possibly brought about unnecessary risks for the enterprises. The currently marketplace has already approached a perceptual consumption pattern. The value of a product is not limited to the function and having an attractive appearance but is also required to correspond to the preferences of the consumers. Therefore, designers must understand consumers' expectation for the best products in their minds. And they must endow a product with the best form, material, and color so that the value added to a product can be enhanced for the most product benefit.

To that end, the usage behavior of users, the functions of the products and the techniques required during the product design stages must first be considered. Form developments were then performed, and this process is the so-called "form follows function". However, this approach is a topic that is worthy of further research with respect to having a method which make products prolific with aesthetic perceptions during form developments so as to attract the consumers. At the same time, design teams are required to continuously survey every detail of a product during form developments so as to make sure the product meets the aesthetic conditions. The purpose of this study is to apply the foundation of aesthetics to the design and evaluation of product forms so as to solve the uncertainty toward the aesthetic perception of the forms during the development of the product forms. The final purpose is to obtain optimized forms that correspond with the requirements by aesthetic perception so as to provide designers with an approach which could shorten a product's development time and enhance its competitiveness in the marketplace.

The current trend for the studies on the quantification of customers' emotional and psychological requirements moves toward the Kansei engineering. This study also used the Kansei vocabularies for the study on the aesthetic measures of product forms as an attempt to understand customers' aesthetic perception of product shapes. Birkhoff [1] was the first scholar to propose applying the quantization of aesthetic measures to fields such as styling, poetry,

* Corresponding author. Tel.: +886 4 23590492x19; fax: +886 4 23594645.
E-mail addresses: chlo@thu.edu.tw, e710710@ms49.hinet.net (C.-H. Lo).

http://dx.doi.org/10.1016/j.aei.2015.06.004
1474-0346/

and music; in this approach, the orderliness and complexity was calculated and served as an index of the aesthetics. Subsequently, Moon and Spencer [2] applied a measure and introduced it into the quantitative evaluation of colors; they called it the color aesthetics measure. The complexity C of the color aesthetic measure is C = (color count) + (hue error of color pair count) + (lightness difference of color pair count) + (chroma difference of color pair count). In the past, this approach was firmly believed to encompass the principles of beauty in aesthetics. And he proposed that beauty is based on "Unity in Variety", which reflects the degree of beauty. Birkhoff applied this type of beauty to the quantification of beauty; his theory also applied to cases such as decorations, vases, music, and poetry. In the aesthetic measure equation of Birkhoff (Eq. (1)), M represents the aesthetic measure, O represents the orderliness, C represents the complexity, and the quotient from dividing the orderliness number by the complexity number then represents the evaluation of the aesthetics.

$$M = \frac{O}{C} \tag{1}$$

Birkhoff and Japanese scholar Hiroshi Ohchi aimed at the aesthetic theory proposed by Moon and Spencer and constructed an integration of a set of color equations for aesthetic measures that were calculated while using the orderliness and complexity. Davis [3] examined the hypothesis of Birkhoff on 162 psychology students; he asked them to sort 10 polygons by preference, and the result failed to support the claim of Birkhoff. Although this model indeed comprises the important elements of aesthetics, it still tends to be simple. More importantly, it does not supply an interpretative emotional response such as the example that the cross-shaped polygons possibly contain "positively implicit relevance". On the other hand, Tatepsian [4] explained that when this procedure was considered to aim at the form characteristics of the aesthetics, the quotient by dividing the orderliness number by the complexity number then indicates the evaluation of the aesthetics. At the same time, Ngo et al. [5–9] corrected the interface layout design of computer screens by applying a large number of principles of Birkhoff's aesthetic-measure equations and conducted related aesthetics studies. He investigated methods of enhancing the usability of the user interface of a computer, specifically screen-type user interfaces. He proposed that the imagery of users on screen-type user interfaces could be quantized by applying the method of aesthetic-measure measurements, and the correlation of aesthetic-measure elements and the emotional imagery could be found via back-propagation neural networks. Finally, an operational interface of the evaluations was established, and it assists designers in rapidly mastering the perceptions of users with respect to aesthetic-measure elements and then enhances the aesthetic perceptions of the computer screens. Staudek [10,11] discussed a method for the aesthetics measure of Birkhoff to contribute to the aesthetics measurement of the external form of vases by means of the aesthetic measure equation of Birkhoff. He established a plurality of characteristic points along the contours, and these include the terminal point H, the inscribed point V, the vertical tangent point P, and the variation point of the tangent direction T, which are all redefined to improve the measurement equation of Birkhoff.

Greenfield [12] summarized studies that were related to aesthetics in the last couple of years. Birkhoff conducted, in 1928, a study that was related to the measurement of the aesthetic measures [13]. Hsiao et al. [14,15] proposed applying aesthetic measures to the color design of products and did successfully optimized the design process. Hsiao et al. [16] proposed that with the addition of adequate parameters, the aesthetic measures can be transformed into 2D shapes with curves and 3D shapes with curved surfaces. They also proposed calculation models for aesthetic measures of balance, equilibrium, symmetry, unity, and proportion which serve as the basis for evaluating the aesthetics of product shapes for designers. Since there are distinctive 3D product shapes for the evaluation by the aesthetic measures of balance, equilibrium, and symmetry in earlier studies, the equations for calculating these three aesthetic measures serve as the basis for the evaluation in this study.

The genetic algorithm looks for approximately optimized solutions via rules of evolution; this method has been widely applied in many fields of optimization design, such as computer science, electrical engineering, and mechanical engineering. From a design point of view, the design could be viewed as a succession of processes of searching for the best solution. Many factors (such as the material, structure, cost, and usability) are required to be considered during these processes. In the problem-solving process, a very large solution package will be generated as more factors are considered. Remaining to be solved is the topic of finding the optimal scheme to satisfy market demands on the constantly changing markets. Hsiao and Tsai [17] used neural networks to establish the relationship between product feature parameters and the image vocabulary, which was followed by a study on the most ideal product forms. Their approach used the demand vocabularies along with the GA method. Hsiao et al. [18] also applied Quantification Theory Type 1 along with the morphological chart method and attempted to obtain, by using a genetic algorithm, the optimal combination scheme of the styling that corresponds to the customer demands.

Chang and Chen [19] tried to represent consumers' perception of vehicle shapes numerically as values based on the Kansei engineering principles and the relationship between contour characteristics and consumers' image perception can be established and predicted by the back-propagation network (BPN).

In addition, it is required to address a plurality of related factors during the process of evaluating things. At the same time, fuzzy theory is suitable for objectively assessing identical things that are provided with many types of attributes. It is thus called fuzzy combined judgment when there is an influence of many types of factors, when integral considerations and fuzzy factors are involved. For fuzzy theory applied to strategic decisions on product models, Hsiao [20] applied fuzzy theory to strategic decisions on product concepts of fruit juicers.

The purpose of this study is to establish a set of strategic decision systems for evaluations products' aesthetic measures. Additionally, aesthetic-measure principles serve as a foundation that is applied to the optimization of product forms. Aiming at a design procedure, this study provides designers who are in search of the best product form with a type of criterion for evaluating aesthetics. According to the demands of the principles of aesthetic patterns for the market or designers, the genetic algorithm is applied to the search for the characteristics of the best solution. The parameterization of product styling is converged to correspond with the aesthetic forms that are demanded by the market. The time, efforts and resources that are consumed during the design and development processes can be reduced and the competitiveness of the industry can be enhanced.

2. Theoretical background

2.1. Theory of aesthetic measures

Aesthetic measures were utilized in this study as the fitness function of genetic algorithms for the evolution of product styling with an attempt to obtain a solution that corresponds with the best solution in the aesthetics. Six equations for aesthetic measures were used and they are the equations of balance, equilibrium, symmetry, proportion, unity, and minimalist.