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An integrated neuro-genetic approach incorporating the Taguchi method for product design

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ABSTRACT

Product design is a multidisciplinary activity that requires the integration of concurrent engineering approaches into a design process that secures competitive advantages in product quality. In concurrent engineering, the Taguchi method has demonstrated an efficient design approach for product quality improvement. However, the Taguchi method intuitively uses parameters and levels in measuring the optimum combination of design parameter values, which might not guarantee that the final solution is the most optimal. This work proposes an integrated procedure that involves neural network training and genetic algorithm simulation within the Taguchi quality design process to aid in searching for the optimum solution with more precise design parameter values for improving the product development. The concept of fractals in computer graphics is also considered in the generation of product form alternatives to demonstrate its application in product design. The stages in the general approach of the proposed procedures include: (1) use of the Taguchi experimental design procedure, (2) analysis of the neural network and genetic algorithm process, and (3) generation of design alternatives. An electric fan design is used as an example to describe the development and explore the applicability of the proposed procedures. The results indicate that the proposed procedures could enhance the efficiency of product design efforts by approximately 7.8%. It is also expected that the proposed design procedure will provide designers with a more effective approach to product development.

1. Introduction

The advancement of computer and information technologies has successfully influenced many industries to adopt computer-integrated design and manufacturing approaches intended to shorten their design stages and improve manufacturing efficiency and ultimately enhance the competitiveness of their products in the global market. In general, the product quality often depends on the design quality. Currently, quality improvements in product design and manufacturing are especially emphasized. Certain application technologies used for improving the stability of product quality, efficacy, and variety include concurrent engineering, quality engineering, quality design, value analysis, innovation, and failure mode and effect analysis, among others [1-3]. For mass production quality, the designer must consider each aspect of the manufacturing processes. A designer not only acts as a "bridge" between producers and consumers but is also responsible for ensuring good product quality. A remarkable observation is that the division of labor is becoming increasingly detailed in global production technology, and a current trend is for enterprises to incorporate the original equipment manufacturer (OEM) into the integrated design and manufacturing system. During the design process, the accuracy of design information can greatly influence the quality of design decisions. Therefore, the concept of robust decision-making has grown in importance [4]. In quality-oriented design, a crucial topic at the moment is the approach used by the designer to control various types of production technology to obtain better efficiency and product quality. Taguchi [5] noted that quality could be viewed as the loss of social cost after delivery of products to the customers instead of the loss caused by product function. In other words, the criteria used to evaluate the quality of products are based on the functional variation of the products and the total social loss caused by the products. In the general quality concept, the quality of a product is considered good only if its specifications conform to the customer request (within the

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range of permitted error) when dispatched from the factory. As such, the purpose of quality planning is to provide quality design with the same product functions that can be used even under extreme circumstances. In other words, the characteristic function of the products should not vary due to a different use environment. Scibilia et al. [6] applied the parameter design of the Taguchi method to estimation of the influence of the control factors on the effects of noise factors to increase the amount of useful information. Huffman [7] stressed that the Taguchi method greatly improves design efficiency. Generally speaking, the Taguchi method is used to simplify the experimental design process in quality engineering. In the Taguchi method, the experimental result is directly converted to a signal-to-noise (S/N) ratio in decibel units (dB) and is reduced to the optimum terms in the output via multiple signal-to-noise analyses. By confirming the design parameters and choosing the optimum parameter combination, the Taguchi method provides designers with an effective design alternative to improve product quality. Chen and Chuang [8] presented a robust design approach incorporating gray relational analysis and the Taguchi method to obtain the optimal combination of design form elements. Yıldız [9] further developed a new optimization approach based on the integration of an immune algorithm and Taguchi's robust design method to solve shape design optimization problems. However, the experimental factors in the Taguchi method are subjectively established in two or three levels, and the settlement of the value of each level is usually near the original level ±20% [10]. In the Taguchi method, the estimation of the potential optimum levels of all factors is relatively incomprehensive due to the inclusion of the signal-to-noise ratio, and the quality of product design can be affected. In addition, the optimum parameter levels generated using the Taguchi method are confined to the currently established level, but the best parameter level is likely to be established by the existing levels or between the existing levels. As a result, further studies are required to determine whether such an experimental result can provide a better quality product design.

We note that determination of the optimum parameter levels for the most suitable combination of quality design is related to optimization problems. In recent years, the concepts of neural networks (NN) and genetic algorithms (GA) have been introduced to aid in finding the optimized solution for engineering problems. Hirasawa et al. [11] introduced universal learning networks for various parameters to imitate the computing ability of the neural networks in living beings. Chen et al. [12] proposed a back-propagation neural-network-based quality prediction system for a plastic injection molding process that can aid engineers in determining the most suitable parameter settings. Gologlu and Zeyveli [13] applied the genetic algorithm to a parallel-axis two-stage helical gear train problem to minimize the volume of the gear trains for gear drive design. The applications of NN and GA have gradually turned towards the product design improvement. Hsiao et al. [14] combined the genetic algorithm and Kansei engineering methods to assess the styles of product forms. Jung and Yum [15] developed an artificial-neural-network-based dynamic parameter design approach to solve dynamic parameter design problems for optimal settings of the design parameters. Chen and Martinez [16] introduced a heuristic product family planning method based on the genetic algorithm to search for proper tradeoffs in the commonality of the baseline products that satisfy the customer needs. Tang et al. [17] further proposed a parametric approach that used a three-layered perceptron ANN model incorporated with a genetic algorithm and the technique of generalized super-ellipse fitting for product aesthetic design. The abovementioned NN and GA applications have enabled the improvement of the Taguchi method in determining more precise settings for the parameter values. This improvement will greatly enhance the quality of product design, especially from the aspect of component design. Therefore, it may be possible to more effectively develop "better" product designs by providing the product designer with an integrated approach that can generate more suitable design alternatives for evaluation.

To test the optimization of product quality and the product parameter values for an optimum design, the objective of this research is to apply the Taguchi experimental design process in the identification of critical design parameters and levels and subsequently apply an integrated neuro-genetic approach to the determination of optimum design parameter levels such that the designer will generate more suitable products for enhancement of competitive advantage in the global market. A design problem, i.e., the design of an electric fan, will be used to describe the development of the proposed approach and to test the new design procedures. The concept of fractal geometry is also applied in the generation of electric fan design alternatives.

2. Development procedure

In most product design efforts, the designer must clearly define the true nature of specific problems or requirements such that he or she can direct the design effort toward an appropriate design solution. Typically, the design problem is first be presented to the designer in a rather vague form, and the designer must consider both the internal aspects of the product and the external aspects of the environment in which the product will be used. The internal aspects of the design problem are the properties of the product itself. The external environment aspects include interrelated considerations, i.e., consumer opinions, economic limitations, law, technology, human behavior, and product trends. Both the internal and external aspects in the design problem should be carefully considered and restructured to explore their relationships and to ensure that the recommended design meets all of the design requirements. The stages and steps for development of the integrated neuro-genetic approach are briefly discussed as follows:

Stage 1. Use of the Taguchi experimental design procedure

The Taguchi method is used to construct an orthogonal array for the matrix experiment. According to the concept of the Taguchi method, there are five general steps for constructing the matrix experiment:

Step 1. Choice of a targeted product and identification of important or critical design characteristics:

The choice of a targeted product is based on the consideration of the form that specifies the appearance of a product, the product's component patterns, and the functions that determine the product structure. An electric fan design will be used as an example to explore the applicability of the proposed approach in this research. The important or critical design characteristics can be identified from design deficiencies, poor design solutions, market potential, and need for a better solution.

Step 2. Determination of a suitable quality loss function for use as an objective function:

An appropriate quality performance measurement is considered based on the characteristics of the product to be designed. According to the Taguchi method, certain frequently occurring situations in the characteristic quality loss function include the smaller-the-better type, larger-the-better type, and nominal-the-best type; these types can be used as an objective function and directed towards quality performance measurement. Note that instead of using the characteristic quality loss function as an objective function, the Taguchi method transforms