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Modeling customer satisfaction for new product development using a PSO-based ANFIS approach

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ABSTRACT

When developing new products, it is important to understand customer perception towards consumer products. It is because the success of new products is heavily dependent on the associated customer satisfaction level. If customers are satisfied with a new product, the chance of the product being successful in marketplaces would be higher. Various approaches have been attempted to model the relationship between customer satisfaction and design attributes of products. In this paper, a particle swarm optimization (PSO) based ANFIS approach to modeling customer satisfaction is proposed for improving the modeling accuracy. In the approach, PSO is employed to determine the parameters of an ANFIS from which better customer satisfaction models in terms of modeling accuracy can be generated. A notebook computer design is used as an example to illustrate the approach. To evaluate the effectiveness of the proposed approach, modeling results based on the proposed approach are compared with those based on the fuzzy regression (FR), ANFIS and genetic algorithm (GA)-based ANFIS approaches. The comparisons indicate that the proposed approach can effectively generate customer satisfaction models and that their modeling results outperform those based on the other three methods in terms of mean absolute errors and variance of errors.

1. Introduction

Over the past few decades, globalization and an increasing emphasis on customer needs have dramatically changed the business environment of industries. Vigorous challenges have transformed many manufacturers from being production-centralized to being customer-driven ones. Therefore, companies have to study the extent to which their products could satisfy their customer needs. Customer satisfaction has become an important issue that companies need to address while performing new product development. Market analysis is an effective means to understand customer perception towards new consumer products. Data collection tools such as questionnaires and users' interviews can be used in this regard. Based on the survey data, customer satisfaction models can be developed which can be used to identify customer perceptions towards new products and the associated customer satisfaction level. Customer satisfaction has a direct influence on customer retention [1,2]. In this regard, it is crucial to improve customer satisfaction and identify the associated design attributes that would ensure sustained customer loyalty and competitiveness for the firm [3].

Previous studies have attempted to develop customer satisfaction models using statistical regression, fuzzy regression, neural networks, quantification analysis I, and fuzzy rule-based modeling. Chen et al. [4] developed a prototype system for affective design in which Kohonen's self-organizing map neural network was employed to consolidate the relationship between design attributes and customer satisfaction. Hsiao and Tsai [5] proposed a method that enables an automatic product form search or product image evaluation by means of a neural network-based fuzzy reasoning genetic algorithm. The neural network-based fuzzy reasoning algorithm was applied to establish relationships between the input form parameters and a series of adjectival image words. Fung et al. [6] proposed fuzzy rule-based models to relate design attributes to customer satisfaction. Han et al. [7] developed a variety of usability dimensions, including both subjective and objective aspects, and evaluated product usability based on statistically regressed models. These models were then used to identify functional relationships between design attributes and customer satisfaction. At the same time, various techniques have been attempted to model the fuzzy relationships between design attributes and customer satisfaction. Kim and Park [8] suggested a fuzzy regression approach to estimate functional relationships. Chen et al. [9] proposed another fuzzy regression approach, based on asymmetric triangular fuzzy coefficients, to model the functional relationships. The use of non-linear programming to develop

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fuzzy regression models for the functional relationships was proposed by Chen and Chen [10]. However, the above approaches are only applicable to developing linear models; the non-linear terms of models are ignored. Multiple linear regression, which considers non-linear coefficients, was attempted to model the relationships [11]. However, because the model is in a polynomial form and the order of the polynomials is user-defined, the optimal model was therefore not generated. Liu et al. [12] proposed a fuzzy model to examine the customer satisfaction index in e-commerce. They considered a method that would calculate the index based on a five-level quantity table using fuzzy logic. However, the developed model is implicit; in other words, it is a black-box model. Grigoroudis and Siskos [13] developed the Multicriteria Satisfaction Analysis (MUSA) method for measuring and analyzing customer satisfaction. MUSA is a preference disaggregation model based on the working principles of ordinal regression analysis. Based on the survey data, MUSA aggregated individual judgments into a collective value function for quantifying customer satisfaction. The model assumed that the overall customer satisfaction was measured solely with respect to several customer attributes. Grigoroudis et al. [14] further applied the MUSA method to measure the user-perceived Web quality. Park and Han [15] proposed a fuzzy rule-based approach to examine customer satisfaction levels towards office chair designs. They reported that the fuzzy rule-based approach outperformed the multiple linear regression approach in terms of the number of variables used. Similarly, Lin et al. [16] proposed a fuzzy logic model to determine the consumer-oriented mobile phone form design. The experimental results suggest that the fuzzy model outperformed two neural network-based models in terms of the root of mean square errors. You et al. [17] developed the customer satisfaction models for automotive interior material using quantification I analysis, which examined the relatively important design variables and preferred design features. Hence, significant design variables and their values which affect customer satisfaction were identified. In order to generate non-linear and explicit customer satisfaction models, an adaptive neuro-fuzzy inference system (ANFIS) was examined by the authors [18]. Most of the learning algorithms for ANFIS are based on gradient descent. The calculation of gradients in each step is difficult and the use of chain rule may cause a local minimum. This definitely affects the modeling accuracy. Some intelligent algorithms have been introduced to determine the parameter setting of the model for reducing model training errors and testing errors. Unlike traditional genetic algorithms (GA), particle swarm optimization (PSO) possesses memory, therefore, the optimal solution for the swarm in execution can be memorized and the velocity of every particle can be updated in time. Lu and Wang [19] have performed a study and shown that the estimation of parameters for ANFIS based on PSO had better performance than that base on GA. The use of GA and PSO in training product unit neural networks was also studied by Ismaily and Engelbrechtz [20]. The results indicate that PSO can attain smaller training errors and testing errors and less training epoch as compared with GA. PSO-based fuzzy neural network and GA-based fuzzy neural network were also compared in the application of the autonomous underwater vehicle (AUV) [21]. Results of Zhang's research show that the PSO algorithm can achieve faster convergence velocity and less training errors and testing errors than GA in their simulation experiments. PSO-based ANFIS approach has been applied in various applications such as design of an adaptive controller for brushless DC drives [22], obstacle avoidance [23], circuit fault diagnosis [24] and short-term wind power prediction [25]. In addition, the improved PSO with more powerful variants has been introduced into ANFIS in recent years, such as adaptive weighted PSO [26], crossover operator based PSO [27] and perturbed strategy included PSO [28]. In this paper, a new approach to modeling customer satisfaction, particle swarm optimization (PSO) based ANFIS, is described, by which fuzziness of survey data and non-linearity of the modeling can be considered and explicit models for relating customer satisfaction and design attributes can be generated.

The organization of this paper is as follows. Section 2 describes how PSO-based ANFIS is used to model customer satisfaction. Section 3 describes the determination of parameters of ANFIS using PSO and least square estimation (LSE). An example is provided in Section 4 to illustrate the proposed approach. The validation of the proposed approach is shown in Section 5. Finally, conclusions are given in Section 6.

2. Modeling customer satisfaction using PSO-based ANFIS

An ANFIS can be a multi-layer feed-forward network in which the neural network is regarded as the learning mechanism and fuzzy reasoning is used for the mapping of inputs into an output [29]. In this research, a PSO-based ANFIS was investigated for modeling customer satisfaction. The major steps of modeling customer satisfaction based on the PSO-based ANFIS involve the following: (a) data collection using market surveys; (b) generation of fuzzy rules based on the market survey data using PSO-based ANFIS; (c) extraction of fuzzy rules and the corresponding internal models; and (d) formulation of customer satisfaction models by aggregating internal models of fuzzy rules.

The first step in modeling customer satisfaction concerns the design of market surveys and collection of survey results. As there are plenty of publications regarding this step [30], details of it will not be given here. Suppose that market survey data has been successfully collected. The data can be input to an ANFIS in order to generate fuzzy rules. An example of an ANFIS with four layers and two inputs is presented in Fig. 1.

If both inputs, x_1 and x_2, have two linguistic descriptions (e.g., low and high, respectively), a membership function is used to represent each description. Hence, $\mu_i(x_1)$ denotes the membership function for the ith linguistic description of x_1, and $\lambda_j(x_2)$ denotes the membership function of the jth linguistic description of x_2 where $i = 1, \ldots, 2$ and $j = 1, \ldots, 2$. Thus, there are a total of four membership functions for all inputs as defined by the four nodes in Layer 1 (L1). At L2, one rule is used to denote the outcome for each combination of x_1 and x_2; hence, the total number of rules required is $2 \times 2 = 4$. The fuzzy rules can be generally expressed as follows:

$$R_{ij}: \quad \text{IF} \;\; x_1 \;\; \text{is} \;\; \mu_i \;\; \text{AND} \;\; x_2 \;\; \text{is} \;\; \lambda j, \quad \text{THEN} \;\; f_{ij} = p_{ij}x_1 + q_{ij}x_2 + r_{ij}$$

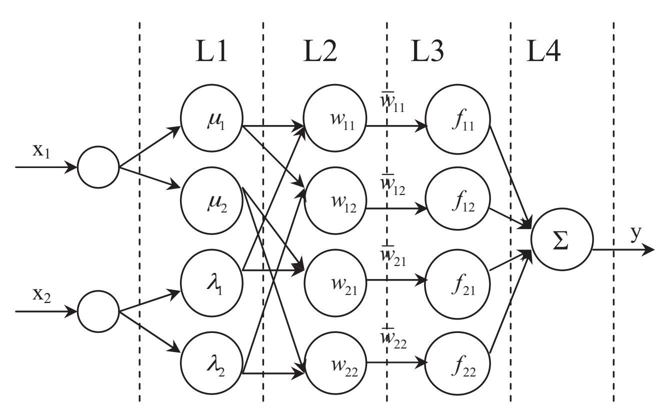

Fig. 1. An ANFIS with four layers and two inputs.