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Fuzzy measurable house of quality and quality function deployment for fuzzy regression estimation problem

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A B S T R A C T

In present competitive environment, it is necessary for companies to evaluate design time and effort at the early stage of product development. However, there is somewhat lacking in systemic analytical methods for product design time (PDT). For this end, this paper explores an intelligent method to evaluate the PDT. At the early development stage, designers are short of sufficient product information and have difficulty in determining PDT by subjective evaluation. Thus, a fuzzy measurable house of quality (FM-HOQ) model is proposed to provide measurable engineering information. Quality function deployment (QFD) is combined with a mapping pattern of "function → principle → structure" to extract product characteristics from customer demands. Then, a fuzzy support vector regression machine (FSVRM) model is built to fuse data and realize the estimation of PDT, which makes use of fuzzy comprehensive evaluation to simplify structure. In a word, the whole estimation method consists of four steps: time factors identification, product characteristics extraction by QFD and function mapping pattern, FSVRM learning, and PDT estimation. Finally, to illustrate the procedure of the estimation method, the case of injection mold design is studied. The results of experiments show that the fuzzy method is feasible and effective.

1. Introduction

As global competition increases and product life cycle shortens, companies try to employ effective management to accelerate product development. However, product development projects are often suffered with schedule overruns. In most cases, problems of overruns were due to poor estimations. That is coincident with the saying "you cannot control what you do not measure" (DeMarco, 1998). In the whole product development process (PDP), product design is an important phase. The control and decision of product development is based on the pre-estimation of product design time (PDT). Nevertheless, PDP always means the brand-new or modified product design. Thus the cycle time of design process cannot be measured directly. Much attention has been focused on reducing the time/cost in product design, but little systematic research has been conducted into the time estimation. Traditionally, approximate design time is determined empirically by designers in companies. With the increase of market competition and product complexity, companies require more accurate and creditable solutions.

Recently, a small number of researches have dealt with the estimation of design time and effort. These existing approaches all belong to the factor analytical method. Using traditional regression analysis, Bashir and Thomson (2001) propose two types of parametric models: a single-variable model based on product complexity, and a multivariable model based on product complexity and severity of requirements. As other factors have not been considered in these two models, the practicability and accuracy are suspectable. Griffin (1997a, 1997b) relates the product development cycle time to factors of project, process and team structure with a statistical method, and quantitatively analyzes the impact of the project novelty and complexity on cycle time. Nevertheless, he does not present an effective method for estimating the design time. Jacome and Lapinskii (1997) present a model for estimating effort for electronic design which takes into account three major factors: size, complexity and productivity. However, this model is applicable only for effort estimation for electronic design. Therefore, there is a demand for more systematic and general methods, which can be applied to a wide range of engineering design projects.

For those nonlinear systems that have many uncertainties, there are no precise mathematic models. Fortunately, adopting intelligent technologies, such as neural network and fuzzy logic, is sometimes a good choice. Jahan-Shahi, Shayan, and Masood (2001) use multivalued fuzzy sets to model the activity time/cost estimation in flat plate processing. Based on neural networks, Seo, Park, Jang, and Wallace (2002) present an approximate method to provide the product life cycle cost in conceptual design.

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Recently, a novel machine learning technique, called support vector machine (SVM), has drawn much attention in the fields of pattern classification and regression estimation. SVM was first introduced by Vapnik (1995). It is an approximate implementation to the structure risk minimization (SRM) principle in statistical learning theory, rather than the empirical risk minimization (ERM) method. This SRM principle is based on the fact that the generalization error is bounded by the sum of the empirical error and a confidence interval term depending on the Vapnik–Chervonenkis (VC) dimension. By minimizing this bound, good generalization performance can be achieved. Compared with traditional neural networks, SVM can obtain a unique global optimal solution and avoid the curse of dimensionality. These attractive properties make SVM become a promising technique (Acır, Özdamar, & Güzeliş, 2006; Bergeron, Cheriet, Ronsky, Zernicke, & Labelle, 2005; Colliez, Dufrenois, & Hamad, 2006; Frias-Martinez, Sanchez, & Velez, 2006; Goel & Pal, 2009; Huang, Lai, Luo, & Yan, 2005; Mohammadi & Gharehpetian, in press; Osowski & Garanty, 2007; Samanta, Al-Balushi, & Al-Araimi, 2003; Übeyli, 2008; Vong, Wong, & Li, 2006; Wu, 2009; Wu, Yan, & Yang, 2008a, Wu, Yan, & Yang, 2008b). SVM was initially designed to solve pattern recognition problems (Acır et al., 2006; Frias-Martinez et al., 2006; Mohammadi & Gharehpetian, in press; Samanta et al., 2003; Übeyli, 2008). Recently, with the introduction of Vapnik's ε-insensitive loss function, SVM has been extended to function approximation and regression estimation problems (Bergeron et al., 2005; Colliez et al., 2006; Goel & Pal, 2009; Huang et al., 2005; Osowski & Garanty, 2007; Vong et al., 2006; Wu, 2009; Wu et al., 2008a, 2008b). In many real applications, the observed input data cannot be measured precisely and usually described in linguistic levels or ambiguous metrics. However, traditional support vector machine (SVM) method cannot cope with qualitative information. It is well known that fuzzy logic is a powerful tool to deal with fuzzy and uncertain data.

For this end, this paper develops a time estimation method for the product remodeling design, which is based on fuzzy logic and support vector regression machine. There is a kind of nonlinear mapping relationship between engineering factors and PDT. SVRM can perform this mapping well. Fuzzy inference theory is introduced to handle the fuzzy input variables. Product characteristics are important parts of engineering factors. As the product characteristics are not available before a product design project begins, this paper attempts to extract product characteristics from customer demands using quality function deployment (QFD) and function mapping methodology. Therefore, the whole estimation method includes three steps: characteristic extraction, support vector machine learning and time estimation. The proposed FSVRM can solve the estimating problem of uncertain fuzzy system. The input and output of the proposed FSVRM are fuzzy numbers.

In this paper, we put forward a new fuzzy inference theory. Based on the fuzzy inference theory and Fν-SVRM, an estimation method for product design time is proposed. The rest of this paper is organized as follows: in Section 2, PDT factors are identified firstly; Section 3 describes a new house of quality (HOQ) model and introduces a mapping methodology to extracting product characteristics; in Section 4, fuzzy support vector regression machine is presented to realize the estimation of PDT; Section 5 presents an example to illustrate the estimation method; and Section 6 is the conclusion.

2. Time factors identification

The PDT estimation method requires a careful selection and identification of the design variables that are related to design time. Therefore, time factors should be confirmed before extracting product characteristics. Many research efforts have been undertaken on the factors of PDP cycle time, but few have done on the product design time. In order to identify the PDT factors, all possible influencing elements incurred in the design process should be investigated and enumerated. Based on the models described for product development cycle time this paper proposes a conceptual model for the relationships between product design time and different factors, as shown in Fig. 1.

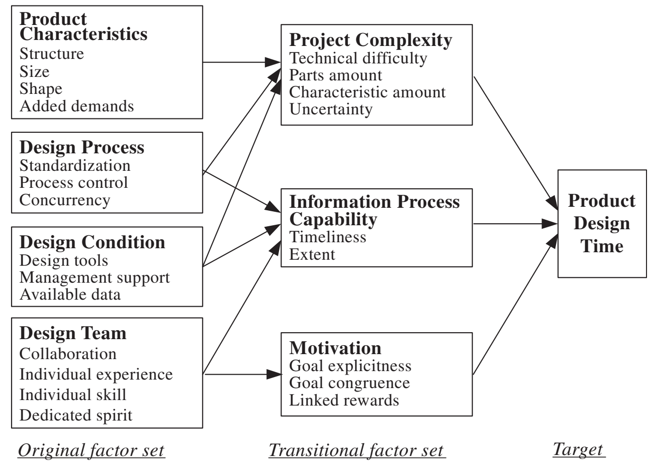

Fig. 1. Conceptual model of factors that influence design time.

In Fig. 1, the original factor set affects the PDT target indirectly via a transitional factor set. The transitional factor set is composed of some factors that are unobvious and difficult to be measured or evaluated. Therefore, only the original factor set is acquirable and will be taken into account in this paper. The original factor set can be sorted into four main subsets: product characteristics, design process, design condition and design team. Here the nonlinear mapping relationship between the original factor set and PDT is realized by a fuzzy support vector regression machine, which will be proposed in the latter part of the paper.

In the original factor set, the factors of latter three subsets can be evaluated directly, while product characteristics must be gained by transforming customer demands before a design process begins. Different types of products have distinct product characteristics. For a specific kind of product, a list of time factors with influencing weights can be determined by analyzing pre-existing design projects. Table 1 provides a sample of time factor set chosen for the design of a gear speed reducer.

3. Product characteristics extraction

QFD is a concept and mechanism for translating the voice of customers (WHATs) into quality characteristics (HOWs) through various stages of product planning, engineering and manufacturing (Prasad, 1998). In the QFD process, a matrix called the house of quality (HOQ) is used to illustrate the complex relationships between WHATs and HOWs. During the QFD transformation, the HOQ is then developed to demonstrate how the quality characteristics satisfy the customer demands (Hauser & Clausing, 1988). Initially, QFD is mainly used to improve product quality and development process. From 1990s, QFD methodology has been extended and can be applied to many specific problems (Cristiano, Liker, & White, 2001; Tsai & Chang, 2004). In this research, HOQ is employed to construct a framework, which helps us to achieve the extraction of product characteristics in the conceptual design or preliminary design stage.

3.1. Fuzzy measurable HOQ

Since there are many subjective and ambiguous evaluations in QFD process, some researchers begin to integrate fuzzy logic