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A data mining approach to dynamic multiple responses in Taguchi experimental design

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Abstract

To simultaneously optimize the parameter robust design of dynamic multiple responses is difficult due to product complexity; however, the design is what determines most of the production time, cost, and quality. Although several methods tackling this problem have been published, they have proven unable to effectively resolve the situation if a system has continuous control factors. This work proposes a data mining approach, consisting of four stages based on artificial neural networks (ANN), desirability functions, and a simulated annealing (SA) algorithm to resolve the problems of dynamic parameter design with multiple responses. An ANN is employed to build a system's response function model. Desirability functions are used to evaluate the performance measures of multiple responses. A SA algorithm is applied to obtain the best factor settings through the response function model. By using the proposed approach, the obtained best factor settings can be any values within their upper and lower bounds so that the system's multiple responses have the least sensitivity to noise factors along the magnitude of the signal factor. An example from the literature is illustrated to confirm the feasibility and effectiveness of the proposed approach.

Keywords: Artificial neural networks; Desirability functions; Simulated annealing; Dynamic multiple responses; Taguchi experimental design

1. Introduction

The robust design has been successfully applied to a variety of industry problems for upgrading product quality since Taguchi first introduced this method in 1980. The objective of robust design is to reduce response variation in products and processes by selecting the settings of control factors which provide the best performance and the least sensitivity to noise factors. To execute the robust design, Taguchi employs an orthogonal array (OA) to arrange the experiments and uses signal-to-noise ratios (SNRs) to evaluate the response of an experimental run. A two-step optimization procedure is then used to determine the optimal factor combination to simultaneously reduce the response variation and bring the mean close to the target value. The robust design method can be applied to problems of both static and dynamic systems. Static systems are defined as those whose desired output of the system has a fixed target value whereas dynamic systems are those whose target value depends on the input signal set by the system operator (Tsui, 1999). Recent reviews of robust design and its applications can be found in Robinson, Borror, and Myers (2004) and Zang, Friswell, and Mottershead (2005).

Although the robust design method has wide applications in practice, it has some limitations (Maghsoodloo, Ozdemir, Jordan, & Huang, 2004). In particular, it can only be used for optimizing single response problems. Several methods have been proposed to resolve multiple response problems (see Derringer & Suich, 1980; Kim & Lin, 2000; Liao, 2005, 2006; Su & Tong, 1997; Tong & Su, 1997; Wu & Chyu, 2004); however, these methods cannot treat the problems of dynamic systems. Recently, several researchers have begun to study robust design problems of dynamic multiple responses. A dynamic system with multiple responses can be represented by a P-diagram (Parameter Diagram), such as that shown in Fig. 1.

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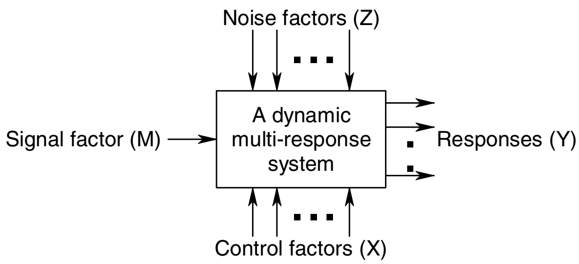

Fig. 1. The P-diagram of a dynamic multiple response system.

The goal is to determine the best settings for the control factors so that simultaneously the system's multiple responses have the least sensitivity to noise factors along the magnitude of the signal factor.

In recent years, there have been a number of articles published which focus on the method of determining the optimal parameter settings of a dynamic multiple response problem. Tong, Wang, Chen, and Chen (2004) adopted principal component analysis (PCA) and the technique for order preference by similarity to ideal solution (TOPSIS) to derive an overall performance index (OPI) for dynamic multiple responses. Wu and Yeh (2005) presented multiple polynomial regression models to minimize the total quality loss of dynamic multiple response systems. Hsieh, Tong, Chiu, and Yeh (2005) employed regression analysis to screen out the significant factors affecting the variation and sensitivity of a system; then, applied desirability function to optimize the parameter design. Wang and Tong (2005) incorporated the TOPSIS into the grey relation model to determine the optimal parameter settings of a dynamic multiple response problem. Moreover, Chang (2006) proposed an artificial neural network (ANN) approach to optimize a dynamic case containing three responses. The approach employed an ANN to construct the response model of the dynamic responses and applied desirability functions to integrate three types of dynamic responses into a single index. The response model was then used to predict all possible responses by inputting full factor/level combinations and to evaluate their indices.

Despite the fact that numerical examples were used to demonstrate the abilities of the above methods, these methods could only obtain the best solution among the specified control factor levels. In other words, they were unable to achieve the real optimal factor combination if the control factors had continuous values. Alternative recent publications have revealed that the data mining approach which integrates ANN and meta-heuristics is a useful method for resolving the problems of continuous control factors (Hou, Su, & Chang, 2006; Hsu, Lee, & Wu, 2006; Huang & Hung, 2006; Su, Chen, & Chan, 2005). Su and Chang (2000) showed the functional relationship between responses and control factors through ANN, and determined the optimal settings of control factors by using simulated annealing (SA). Accordingly, in this work we propose an integrated data mining approach which extends the previous research presented by Su and Chang (2000) and incorporates exponential desirability functions to model and optimize dynamic multiple response systems.

The proposed approach consists of four stages which employ the methodologies of ANN, SA, and desirability functions. First, an ANN is used to construct the response model of a dynamic multiple response system by using the experimental data to train the network. The response model is then used to predict the corresponding responses of the system by inputting specific parameter combinations. Second, each of the predicted multiple responses is evaluated their performance measures (PMs) by using desirability functions. Third, multiple PMs are integrated into an OPI for evaluating a specific parameter combination. Finally, a SA is performed to obtain the optimal parameter combination within experimental region. Applying the proposed approach, the obtained optimal control factor values are no longer restricted to the solution points composed of discrete experimental levels. The proposed approach is illustrated and compared with an example from the literature presented by Chang (2006).

2. Related works

2.1. Taguchi methods on dynamic systems

A dynamic system ideally assumes that a linear form exists between the responses and the signal factors. The ideal function can be expressed as $Y = \beta M + \varepsilon$, where Y denotes the response of a dynamic system, M stands for the signal factor, β is the slope or the system's sensitivity, and ε represents the random error. The aim of the robust design is to find the combination of control factors so that the effect of noise factors on the target response of the dynamic system is as small as possible. To evaluate the performance measure of each experimental run, Taguchi uses dynamic SNR to judge the performance of the responses. The larger SNR means the responses have less deviation from their targets. Differs from Taguchi's dynamic SNR, in this work we intend to develop alternative formulas to measure dynamic performance in order to be applied in dynamic multiple response problems. So, for our purpose the dynamic systems are further classified into dynamic larger-the-better (DLTB), dynamic nominal-the-best (DNTB) and dynamic smaller-the-better (DSTB) according to the desired slope. Hence, the ideal target function is replaced as $Y = \beta_t M + \varepsilon$, where β_t is the desired target slope. For DSTB, DNTB, and DLTB cases, the slope values are $\beta = 0$, $0 < \beta < \infty$, and $\beta = \infty$, respectively. The robust design of the three dynamic cases can be achieved by using Taguchi's two-phase optimization procedure. Fig. 2 depicts the processes of the procedure. The detailed procedure is as follows (Wu & Hamada, 2000):

Phase 1: Select the levels of the significant factors to maximize the dynamic SNRs. A significant factor is a control factor that has an effect on variation.