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Characteristics forecasting of hydraulic valve based on grey correlation and ANFIS

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ABSTRACT

Accurate prediction is crucial for the synthesis characteristics of the hydraulic valve in industrial production. A prediction method (G-ANFIS for short) based on grey correlation and adaptive neuro-fuzzy system (ANFIS) to forecast synthesis characteristics of hydraulic valve is devised and the utilizing of the method can help enterprises to decrease the repair rate and reject rate of the product. Grey correlation model is used first to get the main geometric elements affecting the synthesis characteristics of the hydraulic valve and thus simplifies the system forecasting model. Then use ANFIS to build a prediction model based on the above mentioned main geometric elements. To illustrate the applicability and capability of the devised prediction method, a specific hydraulic valve production was used as a case study. The results demonstrate that the prediction method was applied successfully and could provide high accuracy. The method performed better than artificial neural networks (ANN) to forecast the synthesis characteristics of hydraulic valve.

1. Introduction

The hydraulic valve is a precise assembly product and it is very difficult to control its synthesis characteristics affected by multiple-geometric-element. So, in practice, establishing forecasting model to predict the synthesis characteristics of hydraulic valve is important for both engineers and researchers.

In the course of producing and assembling of the hydraulic valve, process parameters of the valve element, valve sleeve and valve body change unavoidably; which will lead to the synthesis characteristics of hydraulic valve vary in a certain range. So, establishing the forecasting model to predict the synthesis characteristics of hydraulic valve before assembling can decrease the repair rate and reject rate greatly.

It is found that there are nine geometric elements influencing synthesis characteristics of hydraulic valve, including fitting clearance of parts, dimensional precision, shape precision, etc. Because there exist a bit more geometric elements, the current detection method usually measures performance parameters of parts first, and then tests the synthesis characteristics of hydraulic valve after assembling, finally, determine whether the production is eligible or not. Obviously, such a detection process necessarily leads to high repair rate and reject rate. If the complicated nonlinear relationships between the multiple-geometric-element and synthesis characteristics can be learned and memorized by some mathematical models, then the models of the relationships can be used to predict the synthesis characteristics of hydraulic valve in the future. These models will ultimately avail to enterprises. With the developed models, enterprises can determine whether the production is eligible or not before assembling after analyzing the forecast results, so as to decrease the repair rate and reject rate because the complicated nonlinear relationships between multiple-geometric-element and synthesis characteristics have been learned and memorized by the models of the past experiences and examples.

Using grey correlation model to determine the key factors that affect the characteristics of system is an important tool in many researches. Li, Yang, Gelvis, and Li (2006) used a grey correlation model to get the major factors influencing thermal errors of a machine tool so as to simplify the process of modeling. Man, Xia, Chen, and Qiu (2006) also used a grey correlation model to get the main factors influencing the feature of tapered roller bearing. Recently there are lots of methods to predict the characters of a system, such as neural network, grey model, and fuzzy control, etc. Tung and Quek (2002) constructed a kind of adaptive neural network to predict crisp time series. Lin and Lee (2007) improved the GM(1,1) model of grey system, and MFGMn(1,1) model was proposed to predict the rainfall and the price of steel. Han, Sun, and Fan (2008) from DLUT proposed an improved fuzzy neural network model based on T–S model, which can realize high accuracy fitting. There is a rapid growth in the number and variety of applications of fuzzy logic at present. Among various combinations of methodologies, the one that has highest visibility at this juncture is that of fuzzy logic and neural network, leading to so-called neuro-fuzzy systems. One effective method developed by Dr. Jang for this purpose is called ANFIS (adaptive neuro-fuzzy inference system) and the ANFIS technique has already been applied for different purposes such as prediction (Bateni & Jeng, 2007; Bateni,

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Borghei, & Jeng, 2007), knowledge discovery (Huang, Tsou, & Lee, 2006), medical decision making and disease diagnosis (Huang, Chen, & Huang, 2007; Polat & Günes, 2006; Polat & Günes, 2007).

Too many fuzzy rules and parameters consequentially result in training time long of ANFIS model. So, in this paper, grey correlation model is used first to get the main geometric elements affecting the synthesis characteristics of the hydraulic valve, which could simplify the system forecasting model. Then we used the ANFIS to build a prediction model based on the main geometric elements. This will provide more methodological comparisons for synthesis characteristics prediction of a complex system. The prediction method proposed is called G-ANFIS for short in this paper.

The paper is organized as follows. In Section 2, the grey correlation analysis technique is presented and discussed. Section 3 provides a brief description of ANFIS. Section 4 develops an forecasting model (G-ANFIS) using grey correlation analysis technique and ANFIS, and the model is used to predict synthesis characteristics of hydraulic valve, then the results is discussed. Compares its performances with ANN are also made in this section. Conclusions are presented in Section 5.

2. Grey correlation analysis model

In the data processing, grey system theory has the advantage over the traditional statistic theory, namely: its results sufficiently embody the inherent properties of a system with less experimental data and unknown systemic probability (Miao & Xia, 2005). The aim of using grey correlation analysis in this paper is to seek the relationships among all factors in the complex system, and to find out the key influencing factors in synthesis characteristics of hydraulic valve.

2.1. Basic idea

Grey correlation analysis is based on the grey system theory, which is considered to be an analysis of the geometric proximity between different discrete sequences within a system (Deng, 1986; Huang & Huang, 1996). The proximity is described by the grey correlation degree, which is regarded as a measure of the similarities of discrete data that can be arranged in sequential order.

2.2. Basic approach

To get the grey relational degree and the grey relational order, the grey correlation analysis method can be summarized as follows:

Step 1: Get the reference and comparison sequences.Consider one data series:

$$X_0 = (x_0, x_0(2), \ldots, x_0(n))$$

This data series is set as the reference sequence.Then consider m($i = 1,2,\ldots,m$) data series:

$$X_i = (x_i(1), x_i(2), \ldots, x_i(n))$$

These are set as the comparison sequences.

Step 2: Calculate the relational degree.To determine the relational degree between the reference and comparison sequences, a discrete function of the relational degree coefficient (the grey relational coefficient) is represented by

$$\xi_{0i}(k) = \frac{\Delta_{\min} + \rho\Delta_{\max}}{\Delta_{0i}(k) + \rho\Delta_{\max}} \quad (1)$$

where

$$\Delta_{0i}(k) = |x_i(k) - x_0(k)| \quad (i = 1, 2, \ldots, m) \quad (2)$$

is the absolute value of the difference between the two sequences.

$$\Delta_{\max} = \max_i \max_k \{\Delta_{0i}(k)\} \quad (i = 1, 2, \ldots, m;\ k = 1, 2, \ldots n) \quad (3)$$

$$\Delta_{\min} = \min_i \min_k \{\Delta_{0i}(k)\} \quad (i = 1, 2, \ldots, m;\ k = 1, 2, \ldots n) \quad (4)$$

are the maximal and minimal proximity respectively, and $\rho \in [0, 1]$ is the coefficient to distinguish the degree of proximity of X_0 and X_i such that $\xi_{0i} \in [0, 1]$. This value can be adjusted based on the actual system requirements. In this paper, we consider $\rho = 0.5$.After the grey relational coefficients have been obtained, the mean of the coefficients is usually adopted as the grey relational degree. Then

$$\gamma(x_0, x_i) = \frac{1}{n}\sum_{k=1}^{n} \xi_{0i}(k) \quad (5)$$

is called the grey relational degree of the ith comparison sequence x_i to the reference sequence x_0.

Step 3: Order the relational degree.From the ordered $\{\gamma(x_0, x_i)\}$, we shall pick the sequence with the greatest relational degree.

2.3. Standardization disposal of data sequence

Because the meaning and purpose of each influencing factor are different, the target value generally has different dimension and quantitative levels. If the data of two sequences differ greatly in size, the effect of the sequence of small numerical value is easily covered up by the sequence of big numerical value. So, primary data must be disposed to assure the equivalence of all factors (Luo, Zhang, & Li, 2001). The following three ways are adopted to dispose primary data, initial value transform, average value transform and polar difference transform.

Initial value transform is that all data are divided by first data, then get a new data sequence, which has a percentage of the value of different times compared to that of first time; average value transform is that all data are divided by average value and get a sequence which is a certain percent of the average value; polar difference transform is that the larger the number is, the smaller the efficiency is, given as follow.

$$x(k) = \frac{\max_{k\in n} x^{(0)}(k) - x^{(0)}(k)}{\max_{k\in n} x^{(0)}(k) - \min_{k\in n} x^{(0)}(k)} \quad (6)$$

3. Adaptive neuro-fuzzy inference system (ANFIS)

ANFIS is a multilayer feed-forward network which uses neural network learning algorithms and fuzzy reasoning to map inputs

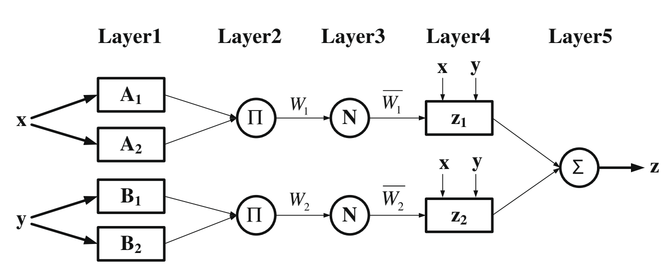

Fig. 1. ANFIS structure for a two-input Sugeno model with two rules.