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Evolutionary neural network modeling for forecasting the field failure data of repairable systems

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Abstract

An accurate product reliability prediction model can not only learn and track the product's reliability and operational performance, but also offer useful information for managers to take follow-up actions to improve the product' quality and cost. This study proposes a new method for predicting the reliability for repairable systems. The novel method constructs a predictive model by employing evolutionary neural network modeling approach. Genetic algorithms are used to globally optimize the number of neurons in the hidden layer and learning parameters of the neural network architecture. Moreover, two case studies are presented to illustrate the proposed method. The prediction accuracy of the novel method is compared with that of other methods to illustrate the feasibility and effectiveness of the proposed method.

Keywords: Repairable system; Neural network model; Genetic algorithms; Reliability prediction

1. Introduction

Many products belong to repairable systems. A repairable system is a system which, after failing to perform one or more of its functions satisfactorily, can be restored to optimal performance without replacing the entire system (Ascher & Feingold, 1987). General mechanic, electrical and communication equipment are all provide examples of repairable systems.

An accurate system or product reliability prediction model can not only learn and track the system or product's reliability and operational performance, but also offer useful information for managers to take follow-up actions to improve the quality and cost of system or product. The reliability prediction model for failure data of a repairable system can be constructed in two ways. The first approach is to select an appropriate probability function as the reliability growth model in advance, then use this model to predict future system reliability. However, a predetermined probability function may fit the failure data well, but the prediction result may not be good in practice. Also, it is often difficult for a reliability engineer to select an appropriate probability function from many existing mathematics probability functions (Liang & Afzel, 2006; Tong & Liang, 2005).

The second approach of constructing the reliability prediction model involves using time series analysis. Ascher and Feingold (1987) suggested that powerful techniques for time series analysis are available for repairable systems. Although these techniques have limited applicability to system reliability, their power makes it worthwhile to ascertain where they can be used (Ascher & Feingold, 1987). Time series methods attempt to recognize the recurring patterns and nonlinear relationships (Azoff, 1994). Traditional time series methods involve autoregressive integrated-moving average (ARIMA) model and seasonal ARIMA (SARIMA) model, and so on. Besides, the neural network model is also employed for reliability prediction because it is capable to analyze and predict time series.

Although artificial neural networks are capable to learn the mechanics of time series, it is difficult to decide network

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structure and learning parameters. However, genetic algorithms can be applied as an optimization search to determine the optimal in neural network structure design including network structure optimization and learning parameters optimization (Liang & Afzel, 2005; Nakhjavani & Ghoreishi, 2006; Whitley, Starkweather, & Bogart, 1990).

Owing to the respective advantages of the neural network model and genetic algorithms, this study aims mainly to employ evolutionary neural network modeling approach to develop a new means of effectively predicting the reliability for repairable systems. Genetic algorithms are used to globally optimize the number of neurons in the hidden layer and learning parameters of the neural network architecture. Results in this study can provide a valuable reference for engineers when constructing quality feedback systems for assessing current quality conditions, providing logistical support, correcting product design, facilitating optimal component-replacement and maintenance strategies, and ensuring that products meet quality requirements.

2. Literature overview

2.1. Nonhomogeneous Poisson process and graph method

Nonhomogeneous Poisson process (NHPP) is most widespread for modeling the number of repairs now. The advantage of using the NHPP model is that the time-between-repairs does not need to be independently and identically distributed. Consequently, NHPP may more closely approach the real world situation in many cases.

Nelson's graph method (Nelson, 1988) can be utilized to analyze the failure data of a repairable system. This method is based on the mean cumulative repair function (MCRF), which is a function of time t. The value of MCRF at time t is the mean of the cumulative repairs at time t. A derivative of MCRF is assumed to exist and is defined as the instantaneous repair rate function (IRRF) (Nelson, 1988). The graph method can be employed to estimate the mean number of repairs and MCRF values for repairable systems. The MCRF value is taken to be the vertical league (y axis), while the time is taken to be the horizontal axis (x axis) on a two-dimensional graph. The slope of the line displayed is the IRRF or failure rate per unit time.

2.2. Reliability prediction

The difference between repairable systems and non-repairable systems is that the reliability of repairable systems largely changes over time and the reliability of non-repairable systems remains stable over time. As above, two methods exist for predicting the reliability of repairable systems. The first method involves selecting an appropriate probability model to construct the reliability growth model, then using this model to predict the repairable systems reliability (Ascher & Feingold, 1987; MIL-HDBK-189, 1981). For example, Webuill process (Webuill Poisson process; power law process) assume that the failures for each system are according to a NHPP with intensity function $\mu(t) = \lambda\beta t^{\beta-1}$, $t > 0$, the intensity $\mu(t)$ is the same mathematical form as failure rate for Webuill distribution (Crow, 1990).

Another method involves utilizing time series analysis techniques to construct an equation representing reliability versus time, then to predict future reliability. Traditional time series methods include ARIMA and SARIMA models (Box & Jenkins, 1976). The advantage of the SARIMA model compared to the ARIMA model is that SARIMA model can deal with data on trends and seasonality. Numerous existing studies of reliability prediction use time series analysis. For instance, Singpurwala (1978) first employed the ARIMA model to analyze the failure data of repairable systems. Furthermore, Singh, Chrys, and Fishwick (1994) developed the failure prediction model for series-parallel complex systems using the ARIMA model. Singh supposed that the predictive power of the ARIMA model is superior to that of other traditional reliability prediction models. Liang and Tong (2001) applied SARIMA model to analyze and forecast the reliability of repairable systems.

2.3. Neural networks and reliability prediction

Besides the above methods, the neural network model can be utilized for reliability prediction. This new wave of neural network activity, restarted at the time of Rumelhart et al. research (1986). Their study researched on the multilayer perceptron neural network architecture with backpropagation algorithm. A neural network model could be considered as a data processing technique that maps, or relates, some type of input stream of information to an output stream of data. In time series application, the input may be a one dimensional time series and the output is the best estimation of the next item in the series.

The back propagation neural network model with gradient descent algorithm is most frequently employed among the neural network techniques. A typical back propagation neural network model with gradient descent algorithm comprises three or more layers, including the input layer, one or more hidden layers, and the output layer. Back propagation is the process backpropagating errors through the system from the output layer towards the input layer during training. The back propagation neural network model with gradient descent algorithm learning minimizes the mean square error between the input data and forecasts using a gradient-descent algorithm. Klimasauskas (1993) supposed that the sigmoid function works best when learning about average behavior and the hyperbolic tangent function works best when learning deviation from the average.

Recurrent networks are also one of the neural network techniques Recurrent networks are neural networks with one or more feedback loops. Unlike static feedforward networks, recurrent networks show dynamics behavior. For instance, they are capable of learning temporal pattern