Applied Soft Computing 24 (2014) 264–276

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

Fuzzy reliability analysis of repairable industrial systems using soft-computing based hybridized techniques

Komal [a,*], S.P. Sharma [b]

[a] Department of Mathematics, Birla Campus, H.N.B. Garhwal University (A Central University), Srinagar (Garhwal) 246174, Uttarakhand, India
[b] Department of Mathematics, Indian Institute of Technology Roorkee (IITR), Roorkee 247667, Uttarakhand, India

ARTICLE INFO

Article history:
Received 27 June 2013
Received in revised form 2 April 2014
Accepted 30 June 2014
Available online 18 July 2014

Keywords:
FLT technique
GABLT technique
NGABLT technique
Nonlinear programming
Genetic algorithm
Artificial neural networks (ANN)

ABSTRACT

The purpose of the present study is to analyze the fuzzy reliability of a repairable industrial system utilizing historical vague, imprecise and uncertain data which reflects its components' failure and repair pattern. Soft-computing based two different hybridized techniques named as Genetic Algorithms Based Lambda–Tau (GABLT) and Neural Network and Genetic Algorithms Based Lambda–Tau (NGABLT) along with a traditional Fuzzy Lambda–Tau (FLT) technique are used to evaluate some important reliability indices of the system in the form of fuzzy membership functions. As a case study, all the three techniques are applied to analyse the fuzzy reliability of the washing system in a paper mill and results are compared. Sensitivity analysis has also been performed to analyze the effect of variation of different reliability parameters on system performance. The analysis can help maintenance personnel to understand and plan suitable maintenance strategy to improve the overall performance of the system. Based on results some important suggestions are given for future course of action in maintenance planning.

Introduction

In recent years, researchers are giving more attention to improve the overall performance of industrial systems (e.g. systems from paper or chemical industries). To maximize the overall performance of the system, it is expected that system will be operational and available for the maximum possible time. However, system failure is unavoidable phenomenon and the causes of failure may be human error, poor maintenance, inadequate testing/inspection or improper use. To reduce the frequency of failures or to enhance the reliability of the system, maintenance personnel give special attention to the types of maintenance action, their frequencies and costs then finally select a suitable strategy. Generally industrial systems are repairable and consist of several subsystems/components. Therefore the probability of system failure depends directly on each of its constituent subsystem/components. Sometimes explicit modeling of system failure/reliability may be difficult due to complexities of industrial systems and nonlinearity in their failure behavior. Under these limitations reliability analysts analyze system reliability with the help of various methodologies like reliability block diagram (RBD), fault tree analysis (FTA), event tree analysis (ETA), petri nets (PN), markov models (MM), failure mode and effect analysis (FMEA), Baysian approach, etc. [1–4]. FTA is a powerful technique used for providing logical functional relationship among components and subsystems of a system and identifying the root causes of undesired events in a system failure [5]. In conventional FTA, it is assumed that exact failure probabilities of events are given or failure data is collected before analysis. The estimation of precise probabilities require large quantity of failure data which adds to the problem and this is due to rare event of its components, human error and economic restraints. Some important events may be omitted during the fault tree construction, which may give incorrect results. Also, it is difficult to obtain past failure data due to environmental change of process and FTA is done at early design stage [6]. Even if data is available (historical), it is often inaccurate, out of date or collected under different operating and environmental conditions because age, adverse operating conditions and the vagaries of manufacturing processes affect each part/unit of the system differently. With raw data, only rough estimates of failure probabilities can be worked out and thus the issue is subject to uncertainty. Some of the main sources of uncertainties in reliability analysis are input parameters uncertainties (e.g. failure rate/repair time, etc.), modeling uncertainties (e.g. numerical approximations, coding error, etc.) and completeness uncertainty [7]. Under these modeling and data constraints, it is very difficult to construct a precise and comprehensive mathematical model for reliability analyses of an industrial

* Corresponding author. Tel.: +91 9410326630.
E-mail addresses: karyadma.iitr@gmail.com (Komal), sspprfma@iitr.ernet.in (S.P. Sharma).

http://dx.doi.org/10.1016/j.asoc.2014.06.054
1568-4946/

system which may be close to real situation. Thus the probabilistic approach to the conventional reliability analysis is inadequate to account for such built-in uncertainties in data. As a result, in real life situation, it is a complicated task to enhance the performance of a system for achieving desired industrial goals utilizing available resources and uncertain data. This is the main reason why there is a growing interest in investigation and implementation of reliability principles for improving industrial systems performance under uncertain environment. Considering these facts, many researchers gave attention on this issue and analyzed various industrial systems behavior in terms of reliability/availability using traditional techniques [8,9]. They analyzed the system without quantifying uncertainties. Knezevic and Odoom [10] extended the concept of Lambda–Tau methodology initiated by Mishra [11] by coupling it with fuzzy set theory and named it as FLT. In their approach, PN is used to model the system while fuzzy set theory is used to quantify the uncertain, vague and imprecise data. Fuzzy arithmetic is used for computing different reliability indices of the system [12]. Sharma [13] analysed reliability of different subsystems of a paper mill using FLT and FMEA. It is analyzed that when FLT is applied for large and complex systems, the computed reliability indices in the form of fuzzy membership functions have wide spread (support) i.e. high range of uncertainty exists [14]. This is because various fuzzy arithmetic operations are used in the computations [12,15,16]. To overcome the problem, Komal et al. [17,18] established a new technique named as GABLT which is based on nonlinear programming approach for evaluating fuzzy reliability indices of repairable industrial systems. It is analyzed that GABLT provides reduced range of prediction of each reliability index at any level of confidence in comparison to FLT. The limitation of GABLT is that it works only for the systems whose components' functional dependencies are precisely known. So, the approach in its current form cannot be used for the systems whose components' functional dependencies are partially known. To overcome the problem, Sharma et al. [19] presented a NGABLT technique based on ANN and applied it for behavior analysis of feeding system in a paper mill. Komal et al. [20] used NGABLT technique for stochastic behavior analysis of forming unit in a paper mill. The major benefit of using ANN is that it can be effectively used in the situations where output pattern is precisely known (supervised) and where output pattern is partially known (unsupervised) [21–24]. In the present study, system components functional dependencies are precisely known, so a three-layer backpropogation with supervised learning is used which has an advantage in processing complicated, non-linear and uncertain data.

The objective of the paper is to analyze the fuzzy reliability of washing unit in a paper mill using available information and uncertain data. FTA is used to model the system and fuzzy is used to incorporate quantitative uncertainty in the analysis. The analysis has been conducted using FLT, GABLT and NGABLT techniques. Some important reliability indices such as system's failure rate, repair time, mean time between failures (MTBF), expected number of failures (ENOF), availability and reliability are computed in the form of fuzzy membership functions using above three techniques and results are compared. The short version of this paper has been presented in the "17th Online World Conference on Soft Computing in Industrial Applications (WSC17)" [25].

This paper is organized in six sections. A detailed discussion on ANN with procedural steps of designed ANN for the present study is given in Section "Architecture and procedural steps of ANN designed for the study". In Section "A brief overview of FLT, GABLT and NGABLT techniques" a brief overview of FLT, GABLT and NGABLT techniques are given. System components working are described in Section "System description". FLT, GABLT and NGABLT techniques are applied to compute fuzzy reliability of the system and comparison with relevant findings are discussed in Section "Result and discussion". Limitations of the present study and a brief future scope are given in Section "Limitations and future scope". Concluding remarks and managerial implications are given in Section "Conclusion".

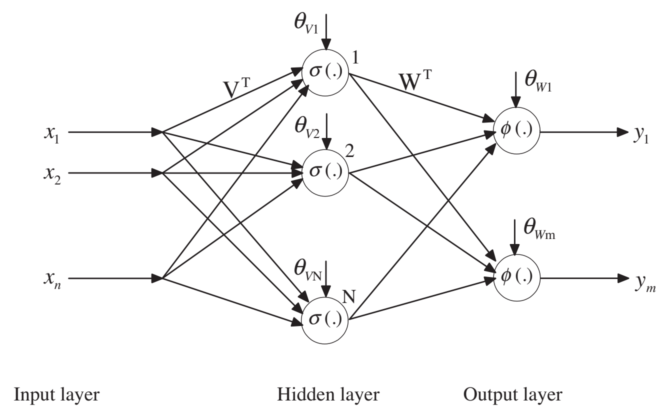

Fig. 1. Model of a feed-forward neural network.

Architecture and procedural steps of ANN designed for the study

A brief idea of architecture of ANN along with basic procedural steps of designed ANN for the particular problem considered in the study are given in this section.

Architecture of a general ANN

A typical multi-layer ANN [21] comprises of

- an input layer, an output layer and hidden (intermediate) layers of neurons to implement arbitrary complex input/output mappings and separating different patterns,
- activation functions attached with input, hidden and output layers that determined the output from the relevant layer,
- a training algorithm to minimize the output error by adjusting network weights and biases.

A three-layer feed-forward neural network with n units in input layer, m units in output layer and N units in the hidden layer is shown in Fig. 1. The complexity of real neurons is highly abstracted when modelling artificial neurons. These basically consist of inputs, which are multiplied by weights, and then computed by an activation function attached with hidden layer which determines the activation of the neuron. Another activation function attached with output layer computes the output of the artificial neuron. To minimize the output error, training algorithm is used. During training weights are assigned to the synapses. Three types of ANN training algorithms are most common: supervised, unsupervised, and hybrid. Our study is based on supervised learning. In supervised learning the ANN is given with a set of inputs and corresponding outputs. Once an input vector is processed, the output obtained is compared to the desired known output. The difference between the two is the error used as the basis to adjust the weights in order to reduce the error. The algorithm is stopped when stopping criterion (maximum number of generations or predefined minimum value of error function) is reached [21,23].

Procedural steps of designed ANN

The procedural steps of designed ANN for the particular problem considered in the present study is given as follows: