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ISA Transactions ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

ISA Transactions

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

Statistical process control using optimized neural networks: A case study

Jalil Addeh [a,*], Ata Ebrahimzadeh [b], Milad Azarbad [b], Vahid Ranaee [b]

[a] Bargh Gostar Baharan Golestan Corporation, P.O. Box 4971684981, Gonbad Kavus, Iran
[b] Faculty of Electrical and Computer Engineering, Babol (Noushirvani) University of Technology, P.O. Box 47135-484, Babol, Iran

ARTICLE INFO

Article history:
Received 15 October 2012
Received in revised form
15 June 2013
Accepted 27 July 2013

Keywords:
Control chart patterns
COA
Neural networks
Shape feature
Statistical feature

ABSTRACT

The most common statistical process control (SPC) tools employed for monitoring process changes are control charts. A control chart demonstrates that the process has altered by generating an out-of-control signal. This study investigates the design of an accurate system for the control chart patterns (CCPs) recognition in two aspects. First, an efficient system is introduced that includes two main modules: feature extraction module and classifier module. In the feature extraction module, a proper set of shape features and statistical feature are proposed as the efficient characteristics of the patterns. In the classifier module, several neural networks, such as multilayer perceptron, probabilistic neural network and radial basis function are investigated. Based on an experimental study, the best classifier is chosen in order to recognize the CCPs. Second, a hybrid heuristic recognition system is introduced based on cuckoo optimization algorithm (COA) algorithm to improve the generalization performance of the classifier. The simulation results show that the proposed algorithm has high recognition accuracy.

1. Introduction

In modern industrial and service organization, control charts have been utilized extensively. Different kinds of control charts have been recently improved according to various quality characteristics and control goals. For the first time, Shewhart proposed using control charts for monitoring process fluctuation in 1924. It is supposed that in a process fluctuation, assignable causes make abnormal changes, while non-assignable causes lead to normal changes. Consequently, automatically recognizing Control Chart Pattern (CCP) is a necessary subject to identify efficiently the process fluctuation [1].

In recent years, several studies have been performed for recognition of the unnatural patterns. Some of the researchers used the expert systems [2,3]. The advantage of an expert system or rule-based system is that it contains the information explicitly. If required, the rules can be modified and updated easily. However, the use of rules based on statistical properties has the difficulty that similar statistical properties may be derived for some patterns of different classes, which may create problems of incorrect recognition. Also, Artificial Neural Networks (ANNs) have been widely applied for classifiers. ANNs can be simply categorized into two groups comprising supervised and unsupervised. Most researchers [4–6] have used supervised ANNs, such as multi layer perceptron (MLP), radial basis function (RBF), and learning vector quantization (LVQ), to classify different types of CCPs. Furthermore, unsupervised methods, e.g. self-organized maps (SOM) and adaptive resonance theory (ART) have been applied to fulfill the same objective in other studies [7,8]. The advantage with neural network is that it is capable of handling noisy measurements requiring no assumption about the statistical distribution of the monitored data. It learns to recognize patterns directly through typical example patterns during a training phase. One disadvantage with neural network is the difficulty in understanding how a particular classification decision has been reached and also in determining the details of how a given pattern resembles with a particular class. In addition, there is no systematic way to select the topology and architecture of a neural network. In general, this has to be found empirically, which can be time consuming.

Most the existing techniques used the unprocessed data as the inputs of CCPs recognition system. The use of unprocessed CCP data has further many problems such as the amount of data to be processed is large. On the other hand, the approaches which use features are more flexible to deal with a complex process problem, especially when no prior information is available. If the features represent the characteristic of patterns explicitly and if their components are reproducible with the process conditions, the classifier recognition accuracy will increase [9]. Further, if the feature is amenable to reasoning, it will help in understanding how a particular decision was made and thus makes the recognition process a transparent process. Features could be obtained in various forms, including principal component analysis shape

* Corresponding author. Tel.: +98 9112761472; mobile: +98 09112761472; fax: +98 1722294632.
E-mail addresses: Jalil_Addeh@yahoo.com, Jaliladdeh@gmail.com (J. Addeh).

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http://dx.doi.org/10.1016/j.isatra.2013.07.018

features [10,11], multi-resolution wavelet analysis [12,13] and statistical features [14]. Pham and Wani [10] introduced feature based control chart pattern recognition. Nine geometric features were proposed: slope, number of mean crossings, number of least-square line crossings, cyclic membership, average slope of the line segments, slope difference, and three different measures for area. The scheme was aimed at improving the performance of the pattern recognizer by presenting a smaller input vector (features). Gauri and Chakraborty [11] also present a set of seven most useful features that are selected from a large number of potentially useful features using a CART-based systematic approach. Based on these selected features, eight most commonly observed CCPs are recognized using heuristic and ANN techniques. Chen et al. [12] presented a hybrid approach by integrating wavelet method and neural network for on-line recognition of concurrent CCPs. In the hybrid system, concurrent CCPs are first preprocessed by a wavelet transform to decompose the concurrent patterns into different levels or patterns, and then the corresponding features are fed into back-propagation ANN classifiers for pattern recognition. The wavelet transform was studied as the input of SVM for CCP recognition in [13]. A Genetic Algorithm (GA) was utilized to improve the recognition performance of SVM. Hassan et al. [14] conducted an experimental study to use BPNs for identifying six types of basic SPC patterns, where the performances of two BPN recognizers using statistical features and raw data as input feature, respectively, were compared. The results indicated that the BPN using statistical features as input vectors has better performance than those of the other BPN using raw data as input vectors. Based on the published papers, there exist some important issues in the design of automatic CCPs recognition system which if suitably addressed, lead to the development of more efficient recognizers. One of these issues is the extraction of the features. In this paper for obtaining the compact set of features which capture the prominent characteristics of the CCPs in a relatively small number of the components, the statistical and shape features are applied. These features are presented in Section 2.

Another issue is related to the choice of the classification approach to be adopted. Literature review shows the systems that use ANNs as the classifiers have high performances [15–17]. Therefore, in the classifier module, several neural networks, such as the multilayer perceptron (MLP) [18,19], probabilistic neural network (PNN) [20] and radial basis function (RBF) [21–23] are used. Then, we propose a novel recognition system based on COA [24] to improve the generalization performance of the classifier.

This study investigates the design of an accurate system for the control chart patterns (CCPs) recognition in two aspects. First, an efficient system is introduced that includes two main modules: feature extraction module and classifier module. In the feature extraction module, a proper set of shape features and statistical feature are proposed as the efficient characteristics of the patterns. In the classifier module, several neural networks, such as multilayer perceptron, probabilistic neural network and radial basis function are investigated. Based on an experimental study, the best classifier is chosen in order to recognize the CCPs. Second, a hybrid heuristic recognition system is introduced based on cuckoo optimization algorithm (COA) algorithm to improve the generalization performance of the classifier.

The rest of paper is organized as follows. Section 2 explains the feature extraction. Section 3 describes neural networks. Section 4 presents the COA. Section 5 describes the proposed method. Section 6, shows simulation results and finally Section 7 concludes the paper.

2. Feature extraction

Automatically recognizing control chart patterns (CCPs) is an essential issue for identifying the process fluctuation effectively. CCPs can exhibit six common types of pattern: normal (NOR), cyclic (CYC), increasing trend (IT), decreasing trend (DT), upward shift (US), and downward shift (DS). Except for normal patterns, all other patterns indicate that the process being monitored is not functioning correctly and requires adjustment. Fig. 1 shows these six types of patterns [1].

In this study, the real Control Chart Pattern database was used and analyzed. They have been collected in the Mehr Cartoon Company.

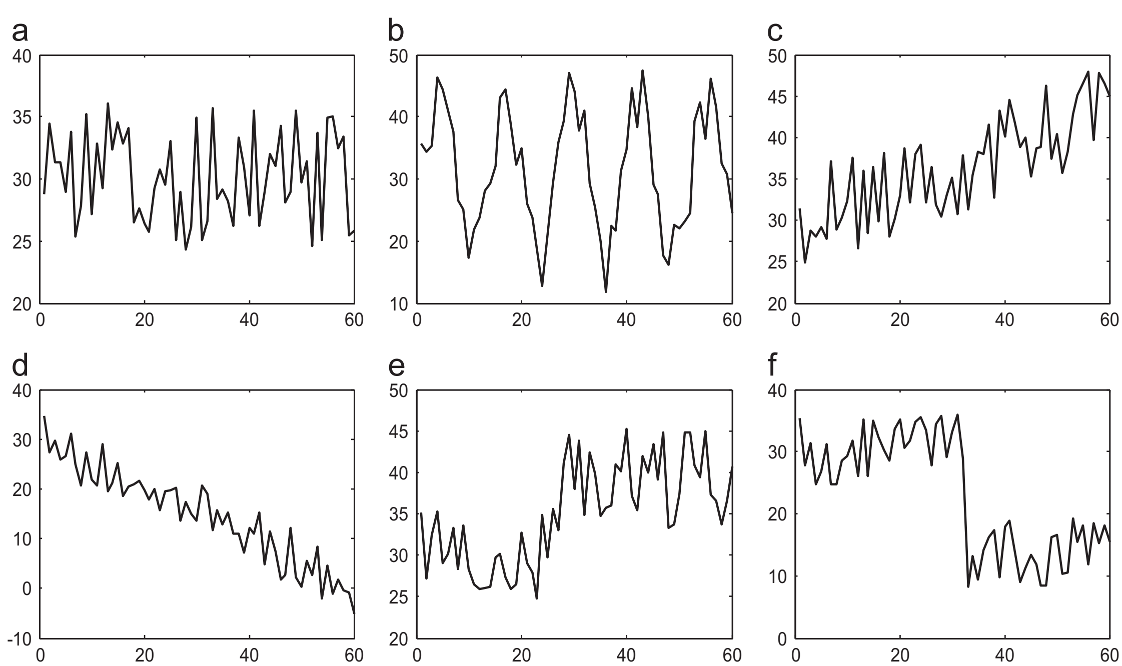

Fig. 1. Six various basic patterns of control charts: (a) Normal pattern, (b) Cyclic pattern, (c) Upward trend, and (d) Downward trend, (e) Upward shift, and (f) Downward shift.

Please cite this article as: Addeh J, et al. Statistical process control using optimized neural networks: A case study. ISA Transactions (2013), http://dx.doi.org/10.1016/j.isatra.2013.07.018