Neural Networks and Control Charts

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Abstract

This analysis is part of the course *Quality and Reliability Control* taught by prof. Stylianos Psarakis in the MSc of Applied Statistics (Part Time). The main inspiration for the structure of this paper and the steps of the analysis, presented below, is taken by his own work [4]. Here we are going to explain how Neural Networks work, what are the Control Charts and how those two topics are connected. Finally we are going to conclude by presenting a summary of this paper.

Neural Networks and Control Charts are two different yet related topics in the field of data analysis and machine learning. Both of them, face certain limitations. Neural Networks appear to give us great performance results so lately researchers decided to use this technique to automate the interpretation of Control Charts. In this analysis, we will take a closer look at both Neural Networks and Control Charts. The advantages and disadvantages will be provided for both of the techniques. Finally we will discuss the potential of combining these two tools in data analysis and quality control.

Contents

1 Introduction

Statistical process control is nowadays the most frequently used tool to monitor the outcome's value of any production, no matter in which industry the outcome belongs to. A part of the statistical process control is Control Charts. Control Charts (CC) are plots that consist of the values that we would like to monitor of a sample taken by the researcher who are responsible for the condition that the outcome of the production line.

Apart from the complexity, researchers have searched for a way to automate the interpretation of the CC and as a result, there were many proposals containing Neural Networks (NN) in order to complete this task. Before diving in the process of the NN usage for the interpretation of CC, we should describe each process in order to establish a common knowledge about both of the aforementioned topics.

2 Neural Networks

Neural Networks are a type of machine learning (ml) algorithm, introduced in 1943 by McCulloch and Pits [3] and inspired by the functionality of the human's brain and its nervous system. As many other ml algorithms, NNs has as a main purpose to identify and indicate patterns in data. They consist of three types of layers (the input, the hidden and the output layers) of interconnected nodes, or neurons. Each connection between the neurons, is associated with a weight that is indicated after an initial process called training. The neurons are connected with each other either fully, or partially.

Fully connected neurons indicate that all neurons of one layer are connected with all the neurons of the next layer and so on so forth. On the other hand, partial connection between the layers indicate that they are not fully connected.

Neural Networks may be trained into with one of the three different ways.

- Supervised Learning
- Unsupervised Learning
- Reinforcement Learning

Supervised Learning :

Supervised learning is when the ml model is trained while knowing what the outcome should be (a.k.a. labeled data) in order to learn to predict new, unseen data. The model is trained to make predictions according to the relationship of the input data and the labels. The algorithm modifies the weights of every option according to the labels of the training data and the prediction in every step until a threshold of error is reached. This type of learning is used for a wide range of ml tasks including image classification, speech recognition and predictive analysis.

Unsupervised Learning :

Unsupervised learning is when the ml model is trained on unlabeled data set and the goal is to discover existing patterns or relationships in the data. In contrast with supervised learning, unsupervised learning is not given and specific goal or output to predict (as labels in data do not exist). As a result, such a model works on its own to find structure in the data on its own. Some of the projects that unsupervised learning is used are clustering, dimensionality reduction and anomaly detection.

Reinforcement Learning :

Reinforcement Learning is an ml methode where the model learns to make predictions by performing actions and observing the results, while receiving rewards or penalties. The goal in this method is to learn the steps (method) that maximizes the reward (or minimizes the penalty) over time. The reinforcement learning has as well many applications some of which are robotics, gaming and recommendation systems.

To sum everything up NNs are capable of handling complex data structures and large amounts of data, making them well-suited for tasks such as image classification, speech recognition, and natural language processing. Let un take a closer look though to the advantages and disagvantages of using Neural Networks for various of task.

2.1 Advantages of Neural Networks

Some of the advantages are the following :

- Neural networks are capable of processing large amounts of data, making them ideal for us to use them in big data application.
- Neural networks are capable of handling data with a wide range of structures and complexity and of course provide an output with patterns recognised or values predicted. The mention here is not just for the handling part of the model, but also for precision of the results generated.
- Neural networks are often able to achieve high accuracy levels in data analysis taks, making them one of the most powerful tools for decision-making.

2.2 Disadvantages of Neural Networks

On the other hand we all know that everything has its own flaws. As a result the disadvantages of NNs are :

- Neural networks can sometimes over-fit to the training data. This could lead to poor generalization performance on new data.
- Everything has its own price. Neural networks require a large amount of computation and memory to train, which can be a hindrance in some applications.
- One other term to refer to NNs is *Black Box.* The reason for that is because NNs can be difficult to interpret. This makes it challenging to fully understand how NNs are making the predictions/decisions.

To visualise a Neural Network model and its parts an image is presented below.

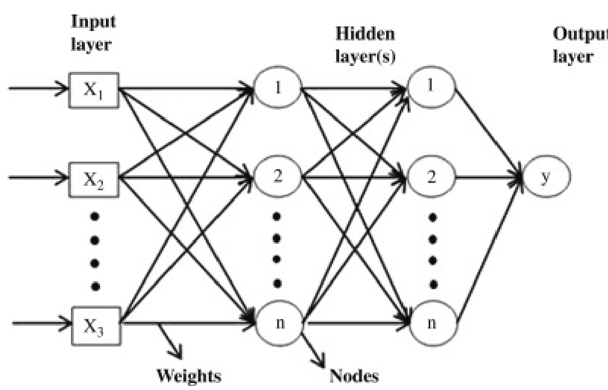

Figure 1: Neural Network Example

3 Control Charts

As stated earlier in this analysis, control charts is a tool that is used in Statistical Process Control to monitor the quality of a process over time. Control Charts were introduced in 1931 by Shewhart [5]. Statistical process control can be used in any production line not only to preserve stability in the quality of the final product but also to establish continuous improvement of the production process in collaboration with experts. Control charts are used to detect changes in process performance, identity special causes of variation, and determine if a process is in a state of statistical control.

A control chart over time, consists of specific components, namely,

- A center line
- An upper control limit
- A lower control limit

The center line, represents the parameter upon which we are to derive a decision whether the process is in control or not. Apart from that the upper and lower bounds help us make this decision. In details, we can say that a point that is plotted between this predefined range, will be indicated as in control. Whereas, a point outside this range will be indicated as out of control. An example is presented below :

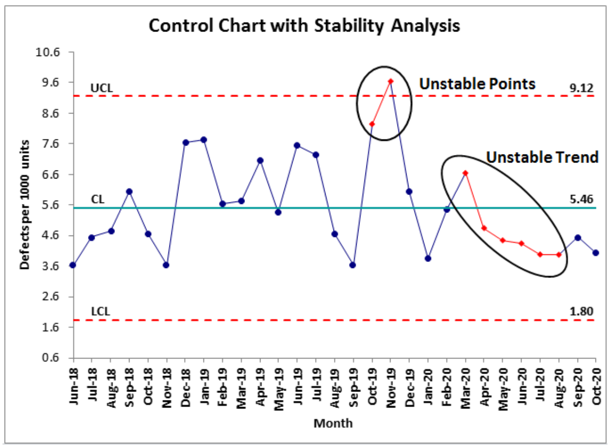

Figure 2: Control Chart Example

The process of using setting control charts into usage is divided into two phases.

Phase I : Retrospective Analysis

- In this first phase, the goal is to set up all the components of control chart and to characterize the whole process with respect to the parameters of our interest. In this process the researcher is requires to collect data from the process and the experts. Apart from that will the researcher, should calculate the control limits, and of course plot the data on the chart, as shown in 3. By the end of this first step, the researcher should have established a center line for the process and determine if it is operating within the expected limits.

Phase II : Monitor

- Once the researcher has characterized completely the process, the next step is to start monitoring it. In *Phase II* the CC that the researcher produced is used to monitor the process and detect any changes in its behavior over time. This is done with the help of the control limits that have been produced in *Phase I* by determining if every sample's parameter estimation of the process over time is within expected limits. If the case is not it, the control chart help the research identify the cause of the change and take action on time.

Keep in mind that *Phase II* is ongoing and the control chart must be continuously monitored and updated to ensure that the process stays in control state. By defining the upper and lower limits properly, control chart can help us detect changes in in a very early stage. As a result, action can be taken on time and correct the mistake before to late.

Control Charts, as well as Neural Networks have advantages and disadvantages.

3.1 Advantages of Control Charts

- Control charts are constructed in a way that they are easy to interpret. This makes it easily understandable and of course understand the flaws in a process and detect any changes occurred.

- Control charts are associated to low cost analysis to implement, which makes this method accessible to organizations of all sizes.
- Control charts are effective at detecting shifts in process performance, which can help identify potential problems before they become serious.

3.2 Disadvantages of Control Charts

- Control charts are limited in their ability to detect complex patterns in data, making them less suitable for handling complex data structures.
- Control charts require a good understanding of statistical concepts, making them less accessible to non-specialists.
- Control charts may not be effective at detecting small changes in process performance, making it difficult to identify subtle problems. Combining Neural Networks and Control Charts

The combination of Neural Networks and Control Charts has the potential to leverage the advantages of both and minimize the disadvantages in any process used. Neural Networks can be used to identify complex patterns in data that are not easily visible by the traditional techniques. The combination analysed in this paper can be particulartly effective in big data applications, where complex and large amounts of data can be processed by NNs to identify patters, and with the help of CCs one can take actions on time to prevent great damage to an organization. Let us now, take a step forward and without getting in the details, try to understand the process of the usage of Neural networks ini the control charts analysis.

4 Interpreting Control Charts using Neural Networks

There may exist numerous applications of Neural Networks related to the topic of Control Charts. In general thought, two of those stand out [2, 1] :

- The first is used to detect deviation in mean and/or variance.
- The second is used to identify strange patters on control charts.

For any of the approaches mentioned above, the NNs are trained to identify several types of out of control patterns such us linear, tread, sudden shift, cycle, stratification, etc. A method described [2], divides the pattern recognition and analysis task into two sequential parts.

I : A general purpose system which was designed and trained to recognize different types of abnormal pattern.

II : A special purpose system structured with several networks which are designed and trained to identify detailed characteristics of the relevan pattern.

In the sequential method described above, a Back Propagation Neural Network (BPN)[1] was used to develop a general-purpose pattern recognizer for three kinds of unnatural process patters i.e. shifts, trend and cycle, as well as the random (normal) pattern of common cause variation. The two error possibilities should be take under consideration while building the design

Type I error : The probability of identifying an unnatural pattern when the process only exhibits common-cause variation

Type II error : The probability of not identifying the unnatural pattern when the process is actually suffering from an assignable cause.

[1]BPN is an algorithm used in artificial intelligence to fine-tune mathematical weight functions and improve accuracy of an artificial neural network's output, for more information visit https://www.techopedia.com/definition/17833/backpropagation.

In this first part of the two sequential parts design, a 3-layer BPN was proposed, in which input layer contained 56 neurons used to input data from 56 consecutive sample data points in a control chart.

On the other hand, in the second part, three separate 3-layer BPNs were used to construct three special-purpose pattern recognizers for each of the three abnormal patterns mentioned earlier *(shift, trend, cycle).* Those BPNs constructed with 56 neurons in input layer, 35 neurons in hidden layer, and only one neuron in the output layer, which outputs the parameter we aim to get out of each network. The process of the two sequential network buildings are presented below.

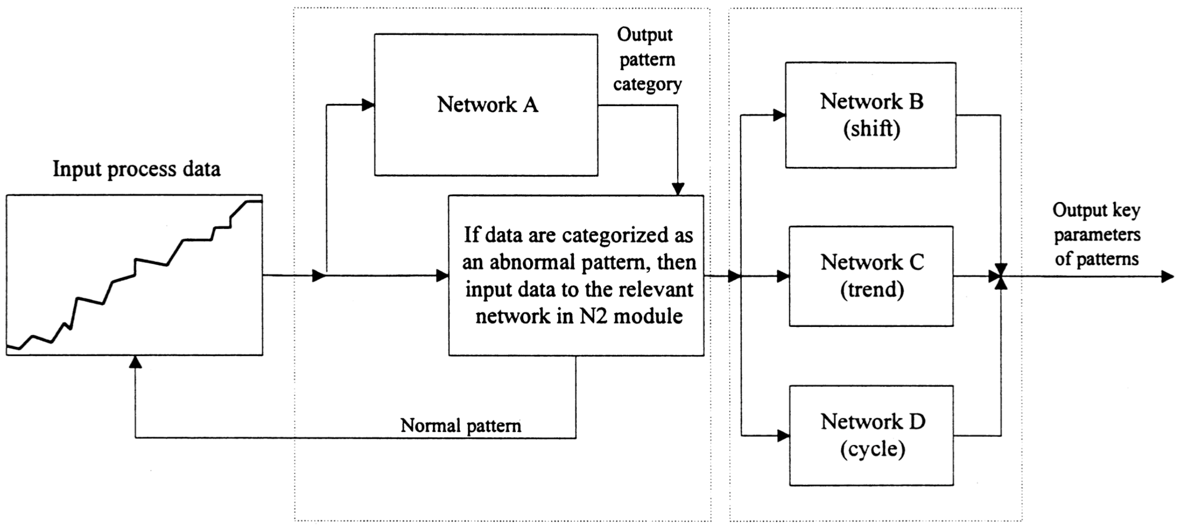

Figure 3: The structure of the model for the recognition and analysis of abnormal control chart patterns

Moving forward, after building the networks proposed, we need to train them with a proportion of the data we obtained, and test them with the rest of them, in order to tune the weights that connects the neurons. This part of the model building is as important as any other decision taken in the process we analyse in this paper.

5 Conclution

Out of control CC patterns can indicate quality problems at an early stage, so the main goal via the usage of the provided methodologies (written above) is to eliminate defects before they are produced. The usage of Neural Networks aim to speed up the process of identifying abnormal patterns in a Control Chart on comparison to the traditional ways. Apart from that when a fine tuned NN is set to use, sub reasons, and minor patterns may be revealed which would not be possible by using traditional ways.

Keeping in mind the pros and cons of neural networks one can only gain in every possible aspect from the procedure described above. Knowing that the process of tuning as well as training and testing may consume a big amount of time, once those steps are completed, we can take the advantage of the speed the output is produced to perform the CC check.

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