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Recognition efficiency enhancement of control chart pattern using ensemble MLP neural network

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Abstract---In this paper, ensemble based the recognition efficiency of control chart pattern for six different fundamental patterns have been proposed. The multilayer perceptron based neural network has applied as an entity to form the ensemble. The loss of generalization property of an individual neural network has been fulfilled by providing the diversity in the training data for the individual entity of ensemble. The outcome of individual recognizer has combined over

their decision value to include the outcome knowledge of each and every entity instead of majority voting of decision. The proposed method has been verified over a large set of data experimentally and observed that there is significant improvement with proposed ensemble approach in compare to individual recognizer.

Keywords---control chart patter, pattern recognition, artificial neural network, ensemble.

Introduction

Control Chart Pattern Recognition (CCPR) is a critical task in Statistical Process Control (SPC). Abnormal patterns exhibited in control charts can be associated with certain assignable causes adversely affecting the process stability. Control charts are important statistical process control tools for determining whether a process is run in its intended mode or in the presence of unnatural patterns. Patterns displayed on control charts can provide information about the process. Control charts have two general uses in the maintaining the quality of the process, the most common application is as a tool to monitor process stability and control and a less common, although some might argue more powerful, use of control charts is as an analysis tool. When a process is stable and in control, it displays common cause variation, a variation that is inherent to the process. A process is in control when based on past experience it can be predicted, how the process will vary (within limits) in the future. If the process is unstable, the process displays special cause variation, non-random variation of external factors. Control charts are simple, robust tools for understanding process variability.

Control chart patterns (CCPs) are important statistical process control tools for determining whether a process is run in its intended mode or in the presence of unnatural patterns. CCPs can exhibit six types of pattern: normal (NR), cyclic (CC), increasing trend (IT), decreasing trend (DT), upward shift (US), and downward shift (DS). Fig1. has shown the typical type cause of faults in CCP and Fig.2 has shown the six fundamental patterns of a control chart. Except for normal patterns, all other patterns indicate that the process being monitored is not functioning correctly and requires adjustment. Identification of unnatural patterns can facilitate early detection of an out-of-control process and the diagnostic search process by narrowing down the set of possible causes that must be investigated. For instance, shift patterns may indicate changes in material, machine or operator, while trend patterns may indicate tool wear. Cyclic patterns may indicate voltage fluctuation in power supply.

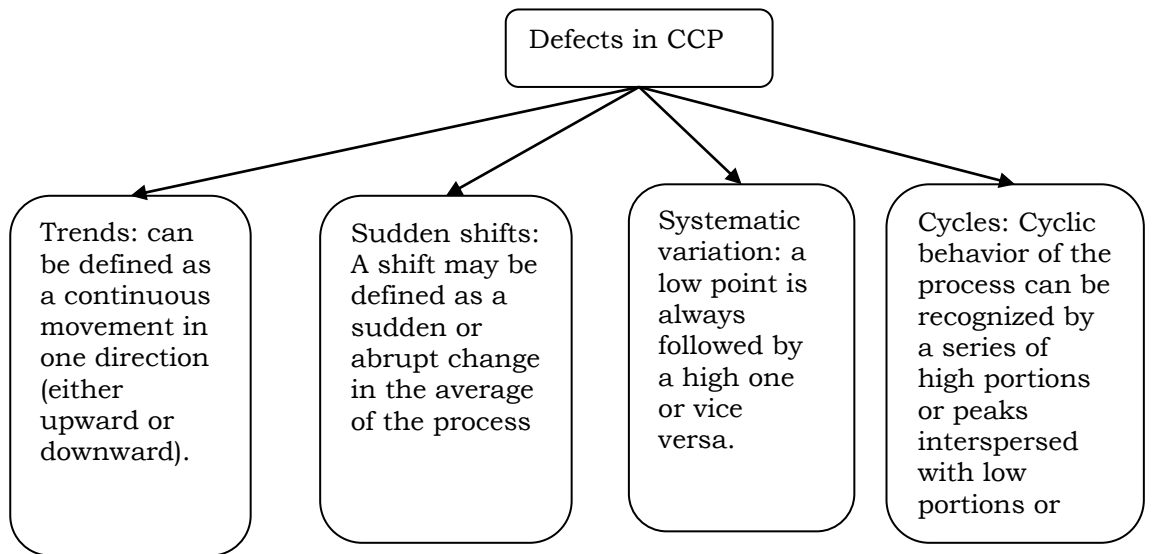


Fig 1. Typical different types of faults in CCP

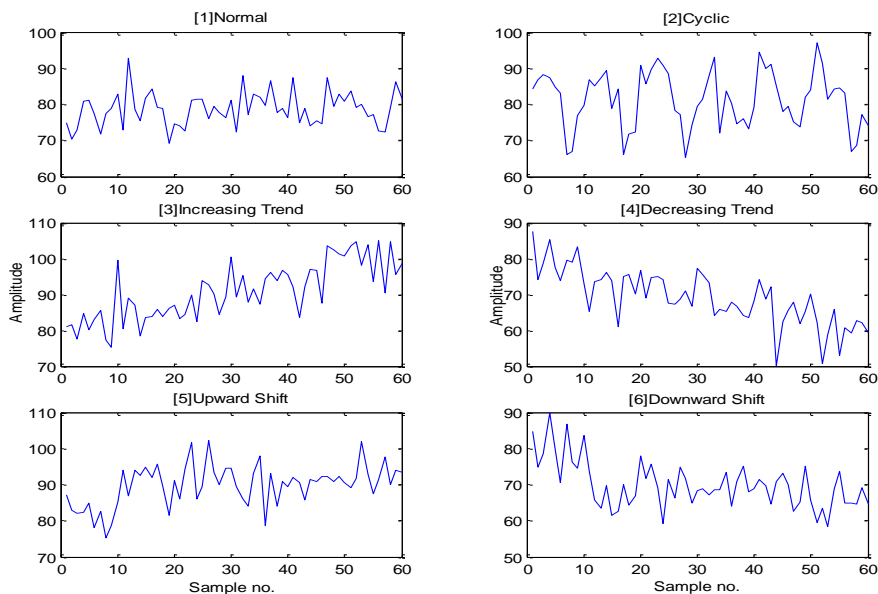


Fig 2. The fundamental patterns on control charts

Materials and Methods

Because of its significant contribution in maintaining the process quality, CCP recognition area has got lots of attention from a number of researchers. A hybrid system based on statistical and shape features and multilayer perceptron neural network (MLPNN) has proposed in [1]. The hierarchical MLPNN system consists of three decision making layers performing a coarse to fine recognition. [2] has proposed a new solution to estimate the number of occupants based on

interactive learning concept using the Multi-Layer Perceptron (MLP) regressor and statistical process control charts to avoid useless interactions with users. Statistical process control charts were deployed to ensure data analysis robustness for the purpose of deciding if an interaction with the occupant is necessary or not.[3] presented a Housing Development Building Management System (HDBMS) strategy inspired by Building Energy Management System (BEMS) concept that will integrate with smart buildings using Supply Side Management (SSM) and Demand Side Management (DSM) System. automatic method based on deep learning and optimization algorithms for nine control chart patterns (CCPs) recognition were proposed in [4].

This method has two principal parts: the classification part and the tuning part. In the last few years, a convolutional neural network (ConvNet) has led to an excellent performance on various tasks, like image processing, speech recognition, and signal processing. Therefore, in the classification part, ConvNet is used as the intelligent classifier for CCPs recognition. One significant difficulty of ConvNet is that it requires considerable proficiency to select suitable parameters like a number of kernels and their spatial sizes, learning rate, etc. The ConvNet parameters have domestic dependencies which make the tuning of these parameters a challenging task. According to these issues, in the tuning part of the proposed method, the Harris hawks optimization (HHO) algorithm is used for optimal tuning of ConvNet parameters.[5] had applied an approach that uses a convolutional neural network (CNN) to extract hidden state-time features to mitigate the curse of partial observability. More specific, a CNN is used as a function approximator to estimate the state-action value function or Q-function in the supervised learning step of fitted Q-iteration. A method of control pattern recognition based on convolution neural network is proposed in [6][10]. CCPR method based on a one-dimensional convolutional neural network (1D-CNN) has proposed in [7].

The proposed method does not require to extract complex features manually; instead, it uses a 1D-CNN to obtain the optimal feature set from the raw data of the CCPs through the feature learning and completes the CCPR. The intelligence of SPC is embodied in the realization of histogram pattern recognition (HPR) and control chart pattern recognition (CCPR). In view of the lack of HPR research and the complexity and low efficiency of the manual feature of control chart pattern, an intelligent SPC method based on feature learning has proposed in [8]. This method has used multilayer bidirectional long short-term memory network (Bi-LSTM) to learn the best features from the raw data, and it is universal to HPR and CCPR.[9] has proposed a two-stage neural network (NN) based scheme to enhance the accurate identification rate (AIR) for MCCPs by performing dimension reduction on disturbance categories. To ensure good quality of input representation, it is important to handle missing values on control charts before feature extraction. Excluding missing values and imputing them with plausible values are two common missing data handling approaches in the literature. In [11] imputation capability of exponentially weighted moving average (EWMA) was investigated.

Incomplete process data for three missingness mechanisms namely, missing completely at random (MCAR), missing at random (MAR) and missing not at

random (MNAR) were investigated using computer simulation. Manual detection of abnormality in control data is an annoying work which requires a specialized person. Automatic detection might be simpler and effective. Various methodologies such as ANN, SVM, Fuzzy Logic, etc. have been implemented into the control chart patterns to detect abnormal patterns in real time. In general, control chart data is imbalanced, meaning the rate of minority class (abnormal pattern) is much lower than the rate of normal class (normal pattern). To take this fact into consideration, [12] has implemented a weighting strategy in conjunction with ANN and investigated the performance of weighted ANN for several abnormal patterns, then compared its performance with regular ANN.

Discussion

Modeling of data generation in CCP:

In order to analyze the CCPs recognition, the Monte Carlo method has used to get the sample data. All patterns except for normal patterns illustrate that the process being monitored is not functioning correctly and requires adjustment. For this study, the patterns of all six basics patterns were generated as shown in Fig.2 using equations as shown in Table 1. Each pattern was taken as a time series of 60 data points. The modeling equations were used to create the data points for the various patterns carrying η as the nominal mean value of the process variable under observation, σ as the standard deviation of the process variable, a as the amplitude of cyclic variations in a cyclic pattern (set to < 15), g as the gradient of an increasing trend pattern or a decreasing trend pattern (set in the range 0.2 to 0.5), b indicates the shift position in an upward shift pattern and a downward shift pattern ($b=0$ before the shift and $b=1$ at the shift and thereafter), s is the magnitude of the shift (set between 7.5 and 20), $r(\cdot)$ is a function that generates random numbers normally distributed between -3 and 3, t is the discrete time at which the monitored process variable is sampled (set within the range 1 to 60), T is the period of a cycle in a cyclic pattern (set between 4 and 12 sampling intervals) and $p(t)$ is the value of the sampled data point at time t .

Table 1
Modeling of CCP and associated parameters values

Control Chart Pattern	Pattern Modeling Equation	Parameters Values
Normal	$p(t) = \eta + r(t)\sigma$	$\eta = 10; \sigma = 5$
Cyclic	$p(t) = \eta + r(t)\sigma + a \sin(2\pi t/T)$	$a = 10; T = 10$
Decreasing /Increasing Trend	$p(t) = \eta + r(t)\sigma \mp gt$	$g = 0.35$
Downward /Upward Shift	$p(t) = \eta + r(t)\sigma \mp bs$ Where $b = \begin{cases} 0 & \text{If } t < L \\ 1 & \text{If } t \geq L \end{cases}$ $L = [U[0 \ 1]] k_2 + k_1$	$s = 12$ $k_1 = 12$ $k_2 = 30$

Ensemble MLP approach of CCP recognition experiment:

Generally it has been observed that, the limited knowledge of a single neural network have some kind of deficiency over the test cases. This happen because of restricted training sample availability. To increase the performance, instead of considering the single neural network, multiple neural networks can be combined in hetero or homo domain. In this work homo domain of architecture has been considered while differences have been appeared in the training data set. Even though there were same number of data samples have considered to acquire the knowledge and learning has given achieve the same mean square error, the differences in the training data will generate the diversity in the acquired knowledge. The recognizer outputs have been ensemble based on mean decision value method where rather than considering the final decision of each recognizer, the delivered quantitative outcome of each recognizer has been considered. This process utilizes the knowledge of each recognizer rather than considering the majority voting where the final decision may not have the outcome of each recognizer. The whole processes of learning and ensemble decision have shown in Fig.3 and Fig.4, Where each control chart pattern recognizer (CCPR) has trained with gradient decent (GD) based learning process.

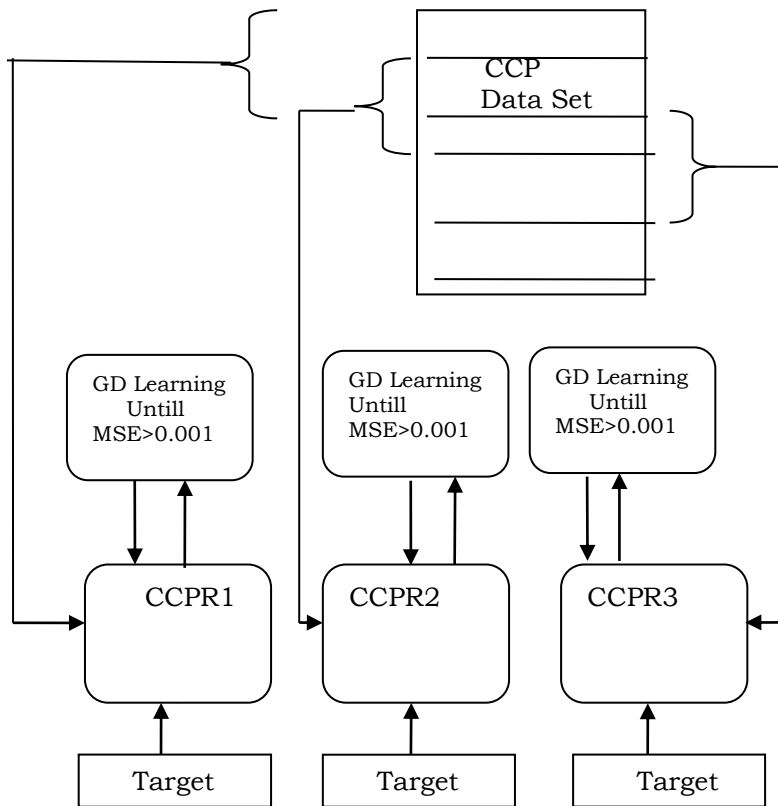


Fig 3. Training phase of recognizers in forming of ensemble

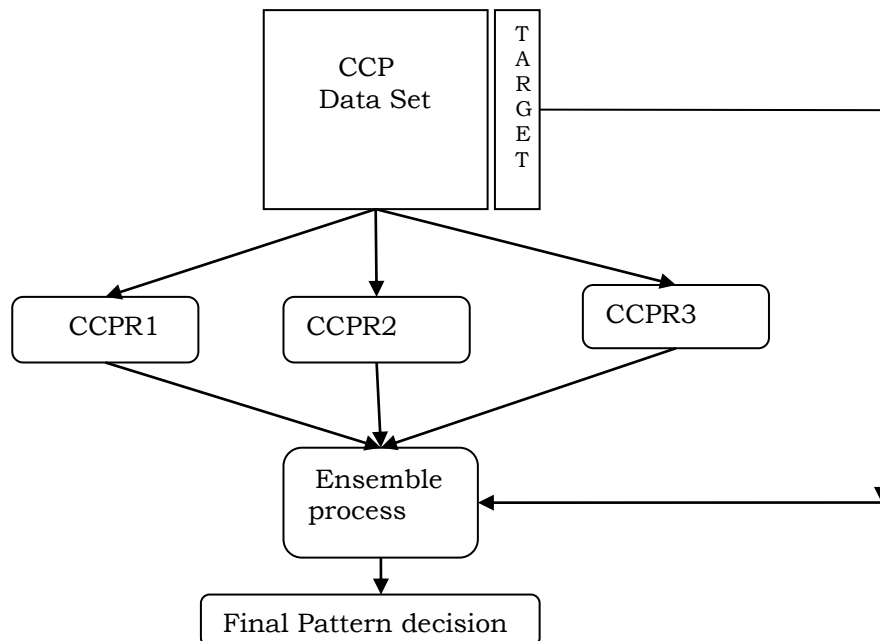


Fig 4. Functional module for ensemble development

Ensemble MLP approach of CCP recognition experiment:

Each recognizer of the ensembles has developed with MLP NN ,where size of architecture were [60 10 6] and got the learning through the gradient decent based approach until the MSE has more 0.001. Pattern data set which contains 3000 pattern has been generated through the model equations. Training and test data set has divided by placing the first 100 set of all six patterns (600 patterns) while test data set contain remaining 2400 data patterns. Each recognizer has a set of training data which carry some different data from others.

The convergence characteristics of learning for all the three recognizers have shown in Fig.5. It can observe that there were some differences in the convergence characteristics which have been occurred because of different training data as well stochastic nature of learning. The performances over the training and test data have shown in Table 2 and Table 3. In table 4 statistical performance of individual and ensemble recognizer has show. It can observe there were very good performance by all in the training case while remarkable difference at the time of test cases. The performance of ensemble has also shown in the Table and can observe that there is very significant improvement has been observed.

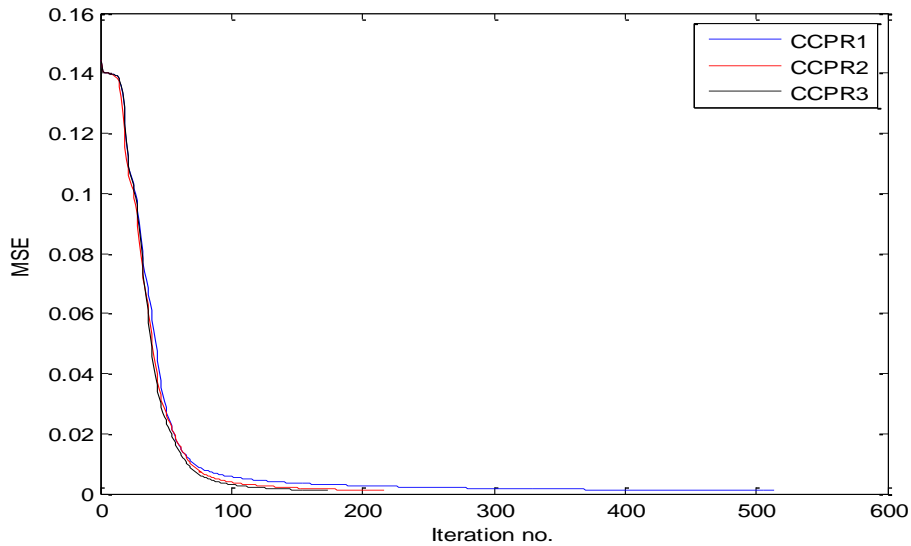


Fig 5. Convergence characteristics of different recognizer for ensemble configuration

Table 2

Correct recognition Performance (%) of individual recognizer over different pattern class for training data

	Normal	Cyc	Incr.	Decr	Up.shift	Dn.shift
CCPR1	100	100	100	100	99.0	99.0
CCPR2	100	100	100	100	100	100
CCPR3	100	100	100	100	100	100

Table 3

Correct recognition Performance (%) of individual recognizer and ensemble recognizer over complete data

	Normal	Cyc	Incr.	Decr	Up.shift	Dn.shift
CCPR1	100	100	100	99.25	99.5	100
CCPR2	99.75	100	100	100	99.0	97.75
CCPR3	100	100	100	99.75	99.5	97.0
ENCCPR	100	100	99.8	100	99.8	100

Table 4

Mean & Std.Dev of individual recognizer and ensemble recognizer performance over complete data

	CCPR1	CCPR2	CCPR3	ENCCPR
Mean	99.7917	99.4167	99.3750	99.9333
Std.Dev	0.3323	0.9037	1.1806	0.1033

Conclusion

The proposed form of ensemble which has used MLP neural network as an entity has shown the remarkable increase the recognition performance of control chart pattern. The use of combining the decision value has made the system very useful in utilizing the knowledge of each and every entity of ensemble. The recognition performance of ensemble was high (average 99.94%) and solution method has easiness in structural and computational point of view. It is also possible to include the different types of structural entities of neural network in ensemble formation as well as some kind of intelligent approach to decide the weight of each entity outcomes.

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