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ENHANCEMENT OF NEURAL NETWORKS NOVELTY FILTERS WITH GENETIC ALGORITHMS

زيادة مقدرة الشبكات العصبيه الصناعيه على اكتشاف المستحدثات باستخدام الخوارزمات الجينيه

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ملخص البحث

يهدف هذا البحث الى تقديم طريقه جديده لاكتشاف الاعطال الناشئه عن قصر فى ملفات المحركات الكهربيه اثناء التشغيل باستخدام تطبيقات الحاسبات الذكيه المبنيه على اساليب الشبكات العصبيه الصناعيه والخوارزمات الجينيه . استخدمت اساليب الشبكات العصبيه الصناعيه فى هذا البحث لقياس الاشارات الصادره عن التيار المغذى للمحرك واكتشاف الغريب منها والذى يفيد بان هناك خلل بالمحرك. وقد استخدمت الخوارزمات الجينيه فى تمرين الشبكات العصبيه الصناعيه المستخدمه فى هذا التطبيق بغرض زيادة قدرتها على اكتشاف الاشارات الغريبه والداله على وجود اعطال فى ملفات المحركات الكهربيه اثناء تشغيلها وقد عرضت نتائج هذا البحث لاثبات فعالية الاسلوب المقدم.

ABSTRACT

In this paper a method for enhancing the capabilities of Neural Networks novelty filters using genetic algorithms is described, and a method for detecting shorted turns in rotating machines using such computational intelligence techniques (neural network and genetic algorithm) is presented. The methods of signal processing and detection of faults in operating machines is discussed. The use of novelty filters for the detection of shorted turns and mechanical failures in operating machines is described. Genetic algorithm has been used to train the neural network to enhance its capabilities as a novelty detector. The proposed technique has been applied on an induction machine and the simulation results have been presented to show the effectiveness of the proposed technique.

KEYWORDS

Neural Networks, Genetic Algorithms, Fault detection

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1. INTRODUCTION

A novelty filter is a system which extracts the new, anomalous, or unfamiliar part of the input data. The term itself was first introduced by kohonen [1] to describe a system which displays the unfamiliar part of the data at the output. A novelty filter is especially useful for detecting faults or other anomalies when data is not available for fault condition, e.g., detecting of shorted turns in large generating machines is a difficult task. Introduction of shorts for testing or training of novelty filters is impractical and costly and so faults must be detected without explicit measurements of signals under the presence of faults.

A novelty filter can be realized by a simple pattern matching algorithm to store replicas of all familiar patterns and then compare the selected pattern with the input at the recall time, the anomaly metric could be the difference between the two vectors.

In this work the neural networks have been applied to novelty filtering of fault detection problem. The novelty detector neural network operates as an auto associative memory where the neural network, normally a two layer feed forward network, is trained to identify the inputs. During training of the network by the proposed algorithm, the output is forced to repeat the input. The output layer must thus have the same number of input values. During operation of the network, the inputs are presented and the output produces the values corresponding to the training input which resembles the current input. The novelty is then the difference between the current input and the output produced by the network. The difference is then compared with a threshold using some form of distance function.

Specifically, if x_i is an n input vectors and $\hat{x}_i$ is the corresponding output, the network is trained to minimize the errors $E = \sum_{i=1}^{n} \|x_i - \hat{x}_i\|^2$.

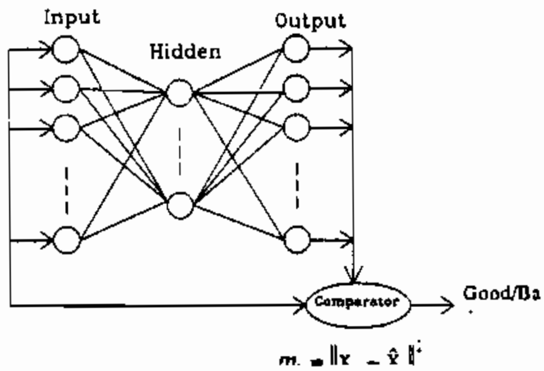

Figure 1 The basic architecture of a Neural Network Novelty filter

Once training is complete, the anomaly metric is $m_i = \|x_i - \hat{x}_i\|^2$ as shown in figure 1.

If the network is trained to reproduce an input vector x in an auto associative memory mode, which means that y(x)=x where y(x) is the output mapping of the input vector, under the assumption that the output is constrained to match one of the training patterns, presentation of a perturbed version

$$\underline{x}^* = \underline{x} + \Delta\underline{x} \qquad (1)$$

should result in finding the best match as

$$y(\underline{x}) = y(\underline{x} + \Delta\underline{x}) = \underline{x} \qquad (2)$$

To enhance the anomalous part of the input, we subtract output from the input. The novelty filter response to the $\underline{x}^*$ is ideally

$$\begin{aligned} n(\underline{x}^*) &= \underline{x}^* - y(\underline{x}^*) \\ &= \underline{x} + \Delta\underline{x} - y(\underline{x} + \Delta\underline{x}) = \Delta\underline{x} \end{aligned} \qquad (3)$$

this is true if $o(\underline{x} + \Delta\underline{x}) = \underline{x}$. Conditions under which equation 3 is valid will be achieved by the new training algorithm presented in the following section.

Several methods for detecting faults in rotating machines has been introduced[3-5]. Although electrical machines are robust, the possibility of faults is inherent in the machine due to stresses involved in the conversion in electrical to mechanical energy and vice vera, so faults in rotating machines will affect the overall performance before it comes to a major failure. Early fault detection allows preventive maintenance to be scheduled for the machine and may prevent extended period of down time caused by extensive motor failure. This will reduce maintenance cost and increase the reliabilty of the machine.

Some techniques for detecting faults in rotating machines require expensive diagnostic equipment for fault analysis , others may require off-line operation to determine the motor condition.

One of the these techniques depends on injecting radio frequency signal to the stator winding of the machine and measure the changes of the output signal waveform to determine whether the rotor windings contains shorted turns. This radio frequency monitoring scheme requires expensive equipment and is justified only for use with large and expensive machines.

Another method depends on the chemical analysis of samples of the motor oil to determine the motor condition, this method is not suitable for on-line fault detection.

Another fault detection method depends on the parameter estimation of the machine through accessible and non-expensive measurements to predict the motor fault condition

In this work, measurement of the current on a single phase of the power supply of induction motor is used to estimate the motor condition, the induction machine is used as an example to show the effectiveness of the system, however the technique is applicable to other kinds of machines. Measurements of the current depends on the assumption that any change in the motor condition will be reflected in the current profile. Any vibration of the motor will cause the rotor to move radially relative to the stator which will cause changes in the air gap, which in turn, induce changes in the current, which will reflect mechanical failure. This way the detector was able to detect electrical failure such as turn-to-turn insulation failure and mechanical failures such as bearing wear. This way a system for on line monitoring of induction motors while the motor is operating could be implemented.

2.Enhancing the Capabilities of Neural Network Novelty Filter

In order for the capabilities of the neural network novelty filter (NF) to be enhanced it should be insensitive to the perturbation in the input patterns after the network has been trained as shown in equation 3.

In this work a new training algorithm for artificial neural networks using genetic algorithms to enhance the NF capabilities is presented. The idea depends on utilizing the genetic algorithms to search the weight space to minimize the total erorr

$$\min_{w} E(w)$$

subject to:

$$\min_{w} \; E(w^{*}) - E(w) \qquad \text{is minimum}$$

Where w^{*} is a perturbed version of w by perturbing each weight and threshold values by +/- Δw.

To discuss the functionality of novelty filters in more details, we start with discussing the internal representation of information, each node in the input layer has linear activation, and those in other layers have sigmoidal activation function defined by:

$$f(x) = \frac{1}{1+e^{-x}} \qquad (4)$$

The relationship between input and output of each processing node is

$$net_i = \sum_{j=1}^{n} w_{ij} y_j + \theta_i , \quad y_i = f(net_i) \qquad (5)$$

where n represents the number of nodes in the preceding layer, w_{ij} denotes the weight from the j-th node in the preceding layer to the i-th node in the current layer, θ_i is the bias of the i-th node in the layer, for simplicity we will consider the bias as a weight with input =1, y_i is the activation of the i-th unit.

The objective of training phase in the backpropgation algorithm is to minimize the sum of square error defined by:

$$E = \frac{1}{2}\sum_{p=1}^{P}\sum_{i=1}^{n}\left(t_i(p) - y_i(p)\right)^2 \qquad (6)$$

where $t_i(p)$ denotes the p-th learning (desired) pattern for the i-th output node, $y_i(p)$ is the actual output. The weights and threshold values are adjusted during learning.

Here we define the novelty filter performance as the ability to identify patterns not shown at training as patterns disturbed by noise with the original learning patterns. As the representation of the novelty filter performance, the change of the output unit with the change in input should be minimal. The change of the k-th output unit by the change in the i-th input can be represented as

$$\Delta y_{ki}(p) = \frac{\partial y_k(p)}{\partial i_i(p)} \qquad (7)$$

where Δy_{ki} is the change in the k-th output due to a change in the i-th input of the p-th pattern, which can be rewritten as

$$\Delta y_{ki}(p) = \frac{\partial y_k(p)}{\partial net_k(p)}\frac{\partial net_k(p)}{\partial yh_j(p)}\frac{\partial yh_j(p)}{\partial neth_j(p)}\frac{\partial neth_j(p)}{\partial i_i(p)} \qquad (8)$$

where net_k, $neth_j$ is the weighted input sum of the k-th output node and the j-th hidden layer node respectively, yh_j is the activation of the j-th node of the hidden layer. Thus it can be rewritten as

$$\Delta y_{ki} = f'(net_i(p))\sum_{j=1}^{n_2} w_{kj} w_{ij} f'(neth_i(p)) \qquad (9)$$

where w_{kj} and w_{ij} is the weight to the hidden layer and output layer respectively, n_2 is the number of nodes in the hidden layer. From the previous analysis to make Δy_{ki} small in order to improve the novelty filter performance, the following conditions must be satisfied

1 - minimize weights w_{kj}, w_{ji}

2- minimize derivatives of the output and hidden units $f'(net_k(p))$, $f'(neth_j(p))$

Weights are restricted by the proposed training algorithm to be as small as possible. Since the training algorithm ensures that the output of a unit has minimal change to the change in parameters (weights), and since the change in the input is scaled by the parameters, and the network is successive transformation of the input, this leads to minimal change in the derivatives $f'(net_k(p))$, $f'(neth_j(p))$. The condition required for equation 3 to be valid. In the following section the use of NF for fault detection and simulation results will be discussed.

There are some different ways in which Genetic Algorithms can be incorporated to train ANNs and to optimize its structure [6-8]. The way the genetic algorithms has been used in this to train Neural Networks subject to the previously explained constraints can be summarized as follows, and more details can be found in [8]:

1- The ANN structure used in this work is the fully connected feed forward multilayered network (Input, hidden, and output).

2- Interconnection weights of the network are encoded as a binary stream in the chromosome of the Genetic Algorithm.

3- Genetic operators are applied in the way described in figure 2, until convergence.

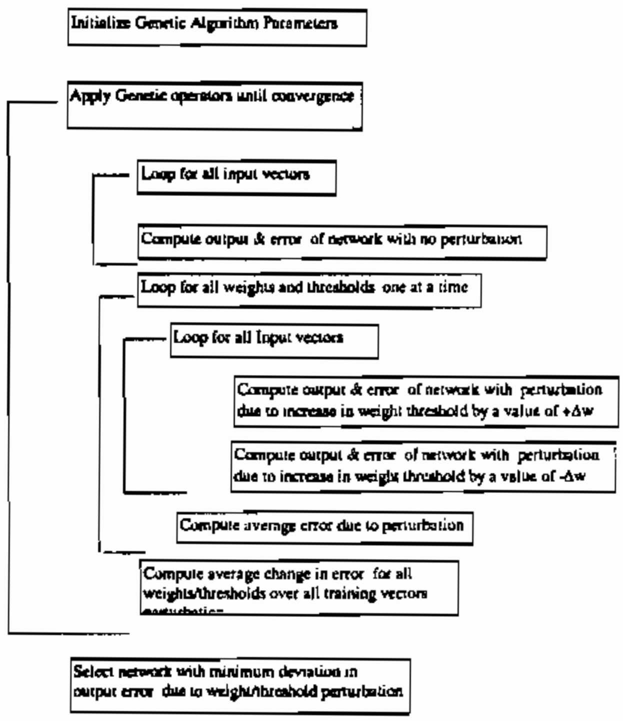

Figure 2. Training Neural Networks with Genetic Algorithms subject to enhance its capability for novelty detection

3. Novelty Filter for Motor Fault Detection

As described earlier the system for monitoring and detecting anomalies or faults in operating motors depends on collecting spectra from the motor while it is operating normally. These spectra is used to train neural network, once trained the novelty filter compares it with new spectrum to determine how similar to or different from the training set it is. This similarity is described by an anomaly metric which, in the simplest case, can be thresholded to determine the motor condition.

The procedure followed to test the functionality of the proposed system is:

1- A set of training examples, obtained from a detailed numerical simulation of the dynamics of induction motor, the current spectrum is then digitized, preprocessed to reduce the effect of noise and to reduce the effect of transient disturbances, because the system is designed to monitor the motor during operation.

2- The current is recorded at different operating conditions and load types of the healthy motor.

3- The collected current spectra is used to train the neural network novelty filter using the proposed training algorithm

4- A set of test patterns, obtained from the simulation program simulating different failures representing electrical and mechauical failures were used to test the novelty detector.

5- Results of the novelty detector trained by the proposed algorithm is collected and compared with that trained by conventional back propagation for the same network architecture. The results showed that the proposed training algorithm outperformed the conventional Back propagation technique in detecting anomalies in the current spectra which can be summarized in the following table.

Condition	Performance	
	Backprop. Technique	Proposed Technique
Fair Bearing	98%	100%
Fair Winding	89%	100%
Bad Bearing	87%	99%
Bad Winding	89%	99%
Unbalanced	78%	100%

Table 1 Comparison of the performance of the proposed technique for training of novelty filter with the conventional back propagation.

As shown in table 1, the proposed algorithm for enhancing the neural networks novelty filter outperformed that trained using conventional backpropagation algorithm.

4. CONCLUSION

It can be concluded from this work that the proposed training algorithm for neural networks using genetic algorithms enhances its capabilities as a novelty filter. The novelty filter has been applied to the problem of detection of shorted turns in rotating machines and the results showed better performance over the neural networks trained using conventional backpropagation algorithm.

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