The Damage Identification of Power Transmission Tower Using BP-AdaBoost Model

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ABSTRACT

The damage identification method of transmission tower based on lift wavelet packet transform and BP-AdaBoost model is developed according to damage feature of bolt looseness of flange connection. Firstly, the vibration signal of structure is decomposed based on lift wavelet packet (WP) transform, then the corresponding damage characteristic vector is established by the lift WP component energy, which will be acted as the sample of BP-AdaBoost model. Finally, the BP-AdaBoost (Back Propagation neural network, the Adaptive Boosting) model is used to identify damage. For comparison, the damage identification methods based on fuzzy clustering and BP network are also studied. In order to verify the proposed method, the experimental research on a simple three-story transmission tower model shows that the proposed method can be effectively used to identify structural damage.\(^1\)

INTRODUCTION

The main component of transmission tower structure is the steel pipe, which are connected by the flange bolt. The bolt will produce loose in the long-term wind-induced vibration and cause bolt joint damage, if which are not found, the injury expansion even leads to collapse of the structure in the strong wind, so it is necessary to diagnose damage of flange bolt looseness.

The bolt looseness recognition problem of transmission tower is highly nonlinear complex system, the introduction of the BP neural network method

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provides a new means for damage identification of engineering structure[1], but the BP neural network algorithm facing local minimum, slow convergence speed, the number selection of hidden units without reference to the principle, which leads to inaccurate damage identification. Li Zuo and Zhang Rui[2] improved BP network by variable learning rate and additional momentum method, which avoid the problem of local minimal, but did not improve the training speed. Adaboost is a kind of iterative algorithm, the main idea is to train different weak learning for the same training set, then these weak learners constitute a strong learner to improve the generalization ability of the algorithm and the prediction accuracy, the algorithm does not require prior knowledge of the weak Learning algorithm which lower limit of prediction accuracy, so it is very suitable for practical problems [3].

According to the present situation of the low accuracy of prediction algorithm, the flange bolt looseness damage identification method of the transmission tower based on AdaBoost algorithm and BP neural network is proposed in this paper. By using lifting wavelet packet analysis, the vibration signal before and after the flange bolt looseness are decomposed, and wavelet packet energy are extracted as the damage vector, which are used to establish BP-AdaBoost model to identify the structural damage. The experimental results show that the method is feasible.

BP Neural Network Prediction Model based on Adaboost Algorithm

Based on the BP neural network, the different parameters are selected to construct multiclass BP weak predictor, and then the Adaboost algorithm is used to obtain several weak predictor which can be formed a new strong predictor.

The specific steps are as follows[4]:

(1) Sample data selection and network initialization

When the iteration number \( t = 1 \), the weight distribution

\[
D_1(i) = 1/N \quad i = 1, 2, \ldots, n
\]

(1)

\[
W_{t,i,y} = D_1(i)/(k-1)
\]

(2)

There \( n \) is the number of samples in the training set, the initial error rate \( \varepsilon_0 = 0 \). Weight vector \( D \) and the superscript 1 was iteration 1, \( i \) is sample number, \( y \) are all kinds of label which do not contain \( y_i \), namely \( y \neq y_i \); Set the maximum number of iterations \( T \). The network structure is designed according to the dimension of sample input and output, and the BP network weights and threshold \( \phi \) ( \( 0 < \phi < 1 \) ) are initialize Set.

(2) The sample data pretreatment

(3) Predict by BP weak predictor. By choosing different BP neural network function, the BP weak predictor ANN is constructed. For \( t = 1, 2, \ldots, T \)
iteration, the t weak predictor is trained using the BP neural network, which are used to establish regression model.

4) ANN process of the main loop \((t = 1, 2,\ldots, t)\) is called using AdaBoost method, the first t time loop:

First, \(W_t^i = \sum_{y \neq y_i} w_{i, y}^t\), then label the weighted function and the weights of sample distribution.

\[
q_t(i, y) = w_{i, y}^t / W_t^i
\]

\[
D_t(i, y) = W_t^i / \sum_{y \neq y_i} w_{i, y}^t
\]

There \(y \neq y_i\)

Then according to the sample distribution \(D_t\) to train the BP neural network ANN by selecting new sample, a weak classifier will get \(h_t : X \times Y \rightarrow \{0, 1\}\);

Calculation "pseudo error" \(\varepsilon_t\) of \(h_t\), if \(\varepsilon_t \geq 0.5\), set \(T := t - 1\), turn to step (5)

Weight adjustment of test data, which is calculated

\[
\beta_t = \varepsilon_t / (1 - \varepsilon_t)
\]

There \(\beta_t\) is the normalization factor, the categorization weight vector is updated

\[
w_{i, y}^{t+1} = w_{i, y}^t \beta_t^{1/(1+h_t(x_i, y_i) - h_t(x_i, y_i))}
\]

5) output: after T loops, the output of strong forecast function:

\[
H(x) = h_T(x) = \arg \max_{y \in Y} \sum_{t=1}^{T} \left( \log \frac{1}{\beta_t} h_t(x, y) \right)
\]

**Experimental Study**

In order to verify the applicability of the damage diagnosis of transmission tower structure based on lifting wavelet transform and BP-AdaBoost, the experimental study of a simplified transmission tower of three layer structure is finished. The simplified model of transmission tower and the flange number and positions are shown in Figure 1.

In Figure 1 (a), a black label position are the location of flange, a total of 12 flanges. Figure 1 (b) is a scale model on the laboratory platform. In Figure 2 (a), there are six bolts in each flange; in figure 2 (b), F is a harmonic excitation position of a certain frequency in the model test, in each flange, the strain gauge of the outer edge of the bolt position is shown in Figure 2 (c).
In Figure 2 (b) in the excitation position of F, the frequency of harmonic excitation of 20Hz and 6Hz respectively are applied to the transmission tower structure. The strain variation of the junction of 3-1 and 3-8 flanges were tested in Figure 1 (a), the result show that when the excitation frequency is close to the low frequency or the structure frequency, the structure response is more sensitive, and the harmonic curves are roughly the same with incentive. Therefore in the experiment process of transmission tower, the excitation frequency of harmonic excitation 6Hz is selected.

From Figure 2 (a), it can be seen that the flange in the model has 6 bolt connection. To simulate the damage, there are three damage cases for 3-8. Case 1: structure intact; case 2: there is only a bolt looseness in flange; case 3: there is not only a flange bolt looseness, the adjacent two bolts slightly looseness.

**Figure 1. Transmission tower structure model.**

**Figure 2. Flange model, excitation load and strain gauge placement.**

(1) Constructing BP-AdaBoost Model Data based on Lifting Wavelet packet

The Db1 of Daubechies wavelet (DbN) is used as the wavelet packet function, the wavelet packet analysis based on lifting framework was used to
decompose the measured vibration signal, and reconstruction of wavelet packet decomposition coefficient, then the energy of the nodes in the first $j$ layer $i$ node is seen in equation (8)[5]:

$$E(j,i) = \sum_{k=1}^{N} (x'_j(k)^2), i = 1,2,\cdots,2^j$$ (8)

There $x'_j$ is the reconstructed signal of $j$ layer and $i$ node.

Due to structural damage, the wavelet packet components has a great influence on energy, therefore the element vector $T$ is constructed using the structure energy characteristics:

$$T = [E(j,i)], i = 1,2,\cdots,2^j$$ (9)

During the experiment, the harmonic excitation frequency of 6Hz is applied on the structure, and for each damage cases, the 8 groups were collected respectively, and 24 groups strain data will be decomposed to three layer wavelet packet by db1 wavelet, which is divided into 8 bands, and the wavelet packet decomposition coefficients were reconstructed, each band wavelet packet component energy are extracted as BP-AdaBoost model. From the experimental results, it can be obtained that for case 1, 2 and 3, the packet wavelet component energy is concentrated in the low frequency band, which concludes more damage information, especially for the most serious damage of case 3, these characteristics are more obvious.

(2) Damage Identification based on BP-AdaBoost Model

The 24 sets of data were normalized to the original data compression in [0,1], and the training set of each sample are assigned to the same weights distribution. One of the training set is selected randomly to train the first NN1 network, the network structure is $8 \times 6 \times 34$ BP network, learning algorithm is the back-propagation algorithm for error, the maximum learning times is 20000, the learning rate $lr=0.1$, and learning target error is $Err_{goal}=4 \times 10^{-4}$.

24 sets of data from the training network are acted as the test sample, which are used to identify damage of transmission tower based on BP-AdaBoost model and BP neural network model, in order to compare the identification effect, the fuzzy clustering is also used to detect structural damage, the fuzzy clustering number is 3, using the fuzzy C mean clustering algorithm (FCM). Three different damage identification results are shown in Table 1, in which the classification number 1 means case 1, number 2 means case 2, and number 3 means case 3.

From table 1, it can be seen that during the experiment, the experimental conditions, manual operation, monitoring device itself with the environmental temperature, humidity, voltage instability, vibration and other factors which produce small changes in experimental data will be generated in the accidental
error, so the case 1 is classified into case 2 by Fuzzy clustering, but the rest of the damage cases are well identified. Using BP neural network method can only detect one of 24 data, while the BP-AdaBoost model can effectively identify damage of flange node of transmission tower, and which has better anti-noise and can be applied to the damage diagnosis of transmission tower structure effectively.

### CONCLUSIONS

The damage identification methods of transmission tower based on lifting wavelet packet and BP-AdaBoost model is proposed in this paper. The results show that:

1. According to the measured data of transmission tower, the vibration test signal of the structure is decomposed using lifting wavelet packet, the wavelet packet energy component is extracted as the damage characteristic vector, which is acted as the sample set of fuzzy clustering and BP-AdaBoost.

2. The BP neural network is improved using Adaboost algorithm, which improves the generalization ability of BP neural network and adaptability of different flange connecting bolt looseness, the method can be used to identify the damage degree of flange connection.

3. Compared with the method of fuzzy clustering and the BP neural network, the proposed method have fast calculating speed and strong ability to resist noise interference. Therefore it is more suitable for large engineering structure damage detection.

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