Research on ZPW-2000R Track Circuit Fault Diagnosis Based on Neural Network

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Abstract. In view of the situation that the fault monitoring is not timely and the accuracy of fault diagnosis is low due to only indoor monitoring equipment but not outdoor monitoring equipment, an intelligent diagnosis method based on neural network is proposed. Firstly, according to the different operating environment and influencing factors of the track circuit, the method of orthogonal test is designed to obtain the information of each component. There are three kinds of track circuit monitoring variables with complex environmental factors, and then the track circuit fault types are divided into three categories: sending channel fault, receiving channel fault and track fault. On the basis of rapid location of track circuit fault location, 21 kinds of specific fault types are distinguished. The simulation results show that: when using this method for track circuit fault diagnosis, even without outdoor monitoring data, it can quickly locate the location of the fault, and the location accuracy can be up to 100%. When identifying 21 fault types, the accuracy of fault diagnosis can still be up to 90%, the diagnosis rate is high and the judgment is fast, which can assist the field maintenance personnel judge faults accurately and quickly.

1. Introduction

In recent years, along with our country: Railways precede transport in a powerful country, railway system with rapid growth, traffic safety and efficiency problem becomes more and more important, the train running safety of railway equipment has higher requirement on the safety and reliability of track circuit [1]as an important part of railway signal system, is mainly used to achieve orbit takes up clearing examination, integrity checking of train and car communications [2]. Due to laying in outdoor railway track circuit, working environment is complex, fault type number, therefore, how to track circuit system fault detection and processing has been a hot topic in the research of scholars both at home and abroad in recent years [3], the railway departments in our country has gradually established a centralized monitoring system for railway signal real-time monitoring, important data of track circuit is running state electricity maintenance personnel to track circuit as well as the main basis of track circuit fault detection, but due to the amount of data, data analysis to add to the larger field staff workload, although there are some fault diagnosis ability, but the misdiagnosis rate is higher.

With the development of big data, artificial intelligence, deep learning is finding wider and wider application in fault diagnosis, the convolutional neural network as one of deep learning algorithm, solves the BP (back propagation) neural network and other traditional network easy to fitting, the extracted features missing such as defects, which can effectively reduce the complexity of the network, has stronger classification ability [4]. Because of track circuit of microcomputer monitoring data is one-dimensional, so in this paper, a one-dimensional convolutional neural network based fault
diagnosis model of track circuit, in the current railway range widely laid no insulation ZPW - 2000 series frequency shift track circuit as the research object, first of all, on the basis of in-depth analysis of the circuit principle, design of orthogonal test method can obtain various complex contains track circuit operating conditions of indoor microcomputer monitoring data; Then, in the absence of outdoor monitoring data, by analyzing the common fault types of track circuit in practical work and combining the circuit principle and practical work experience, the fault types are divided into three categories, namely, sending channel fault, receiving channel fault and track fault, and then divided into 21 specific fault types. Build a reasonable neural network model, through the simulation experiment can be obtained, the fault diagnosis model proposed in this paper has a high accuracy, can assist the field maintenance personnel to accurately and quickly judge the fault.

2. Convolutional Neural Network
Convolutional Neural Network (CNN), a feedforward Neural Network proposed by the mammalian visual cortex cells, is widely used in the field of image recognition [5]. The basic structure includes the input layer, convolutional layer, pooling layer and full connection layer.

One dimensional convolutional neural network is a kind of convolutional neural network that processes one dimensional sequence data. It is similar to the structure of the convolutional neural network, including convolutional layer, pooling layer and full connection layer [6]. When a one-dimensional sequence $X=[x_1,x_2,\cdots,x_n]^T$ is passed into the convolutional layer as an input, the output is

$$x'_j = f\left(\sum_{m=0}^{M-1} X \times k^j_m + b^j\right)$$

(1)

The maximum pooling layer is usually chosen to reduce the sequence length.

$$x'_{p}(k) = \max\left(x'_{(2k-1)}, x'_{(2k)}\right)$$

(2)

The full connection layer, like the traditional neural network, has several hidden layers, and the transfer function sigmoid function can be selected

$$f = \frac{1}{1+e^{-x}}$$

(3)

3. Experimental Scheme Design

3.1. ZPW-2000R Track Circuit Structure
ZPW - 2000R mainly by rail, outdoor and indoor equipment of ZPW - 2000R no insulation transmitter through frequency shift signal frequency shift track circuit to rail transport in the forms of the front section of the vehicle usage when it takes no train, track signal receiver receiving enough strength, track relay suck up, corresponding device shows that the section at leisure interval, when the train into the track circuit train wheel to play a shunt track signal, the orbit of a receiver signal amplitude is lower than the track relay whereabouts threshold, orbital relay, corresponding device shows that the section takes up. [7]

3.2 Orthogonal Test
The different working conditions, orthogonal test design track circuit monitoring variables is different also, as much as possible in order to make the sample data of data contain a variety of contexts, the neural network model is more general, the design of orthogonal test table manner simulation test of orthogonal experimental design using orthogonal table to arrange and analyze a design method of multiple factors experiment[8].Through the analysis of the circuit principle and actual environment determines the four levels orthogonal experiment of five elements, a total of 16 pairs of trials by simulating different faults, the data changes of 15 unit devices such as transmitter, receiver, transmitter
transformer, transmitter tuning unit, receiver transformer, receiver tuning unit, etc. as well as the voltage and current near the rail are monitored and read and recorded by the diagnostic host.

3.3 Fault Diagnosis Model of Track Circuit Based on Convolutional Neural Network

According to the characteristics of supervised learning of the neural network [9]. In the absence of outdoor monitoring equipment, there are few monitoring variables. Therefore, neural network is used to judge the fault of sending channel, receiving channel and track, and then the specific fault types in each category are determined. The model is divided into training stage and fault diagnosis stage. First, real-time monitoring data of the training data set is taken as input, and fault type is taken as output. Parameters of the training network are continuously adjusted to find the optimal parameters.

3.4 Data Processing

In the experiment, there are 14 variables in this section of the monitoring equipment, such as power output voltage, supply current, and cable voltage and current, etc. Meanwhile, the monitoring includes a total of 42 monitoring data of the front and rear sections. According to the circuit principle, the fault types are divided into the following three categories: sending channel fault, receiving channel fault, rail failure. The serial number of the fault name represents each type of fault. By sorting out the data sets of the three fault types, a total of 8490 groups were obtained.

4. Experimental Verification

4.1 Convolution Layer Number Setting

Experimental environment based on the deep learning library Keras, Tensorflow as the back-end, adopt the Anaconda Jupyter Notebook as a python compiler, will input convolution neural network training set, using the method of cross validation is 80% samples as learning samples, 20% sample as a back inspection sample, according to different convolution neural network model, need to choose different optimizer, commonly used optimization method with Adam, RMSprop, SGD, Adadelta [10], etc. Due to the fault diagnosis problems the classification number is more, so choose Adam method, its advantage is to make the gradient after offset correction, the vector each iteration has a fixed scope, parameter is smooth, can speed up the training speed as the input vector is one dimensional data, thus set a one-dimensional convolution kernels by adjust the structure of the convolution layer found selecting convolution kernel size is 3 * 1, the sample width is 2 * 1 highest accuracy of each layer by convolution using Rule activation function characteristics, adopt the method of MaxPooling pooling layer. Alternately, convolutional layer and pooling layer can deepen the depth of the network, and more comprehensive features can also be extracted with fewer parameters. Finally, softmax classification function is used to obtain the classification results.

4.2 The Results

(1) First of all, will be good training sample data were divided into 10560 groups (including three types of failure data of 8490 and 2070 normal sample data group) as the input of neural network net1 will send channel fault receiving channel rail failure and normal as four output of neural network, the iteration after 100 stop training, at this point to check sample accuracy was 99%, and the loss function change curve in the process of training, are shown in figure 1, 2 below. After that, the test samples are input into the trained network, and the accuracy rate of the neural network can be evaluated. The accuracy rate of each type of fault test set can reach 99%.
Using four indicators to analyze the performance of the model, respectively is: the precision rate and recall rate and accuracy, and F1-score [11] among them, the overall classification accuracy evaluation of network performance, the precision rate and recall rate, and F1-score for each type of fault can be seen that network the classification performance of TP FP FN TN constitute the specific calculation formula see type (4) - (7): among them, said TP be model in the prediction of are samples, FP said model in the prediction of negative samples, FN said models predict negative samples, TN said the model predicts a negative negative samples TP, FP, FN, TN constitutes the obfuscation matrix. The obfuscation matrix of Net1 is shown in Figure 3.

\[
P(\text{Precision}) = \frac{TP}{TP + FP} \quad \text{(4)}
\]

\[
R(\text{Recall}) = \frac{TP}{TP + FN} \quad \text{(5)}
\]

\[
A(\text{Accuracy}) = \frac{TP + TN}{TP + FN + FP + TN} \quad \text{(6)}
\]

\[
F1\text{-score} = \frac{2 \times TP}{2 \times TP + FN + FP} = \frac{2 \times P \times R}{P + R} \quad \text{(7)}
\]

(2) Will send channel 1792 groups of the training sample data as input of neural network net2, will work out to send plate bolt, sending lightning protection lightning protection simulation network simulation network disk simulation terminal short circuit, sending lightning protection simulation network disk simulation terminal disconnection, send actual cable terminal short circuit, sending the actual cable simulation terminal break the five kinds of fault types as output, such as the iteration stop training after 300 times, at this point to check sample accuracy was 98.8%, and the loss function change curve in the process of training, are shown in figure 4, 5 below. Then, the test samples were input into the trained network, and the accuracy rate of the neural network was evaluated. The diagnostic accuracy rate of the five faults was 90.1%, 98.5%, 100%, 98.9% and 90.7%, respectively. The obfuscation matrix of Net2 is shown in Figure 6.
Will receive channels of 1799 groups of the training sample data as input of neural network Net3, receives the lightning protection network disk to attenuation and wiring between open cavity, receives the lightning protection simulation network terminal circuit, receiving the actual cable tray of simulation break three failure as an output terminal, the iteration after 600 stop training, at this time back to the sample inspection accuracy of 99%, receive training in the process of loss function curve, shown in figure 7, 8 as follows. Then, the test samples were input into the trained network, and the accuracy rate of the neural network was evaluated. The diagnostic accuracy of the three kinds of faults was 96.8%, 97.1% and 100% respectively. The obfuscation matrix of Net3 is shown in Figure 9.

(4)Take 2352 groups of training sample data of track fault as the input of neural network Net4, FBP rail lead wiring short-circuit, FBA rail lead wiring short circuit, FBA rail connection, the JBP rail brings wiring short circuit, short circuit, JBA rail JBA guide rail connection open circuit, receiving side SVA SVA, receiving side short circuit, open primary rail broken rail, rail shunt, small rail broken rail, rail shunt, compensation capacitor break line 13 kinds of fault types as output, the iteration after 600 stop training, at this point to check sample accuracy was 99%, and the loss function change curve in the process of training, 10, 11, as shown in the diagram below. After that, the test samples were input into the trained network and the accuracy rate of the neural network was evaluated. The diagnostic accuracy of the 13 faults was above 99%. The obfuscation matrix of Net3 is shown in Figure 12.
4.3 Comparative Analysis

In this paper, the model of fault diagnosis adopted by the result and literature [12] has used the fuzzy logic reasoning method, literature [12] 8 kinds of common track circuit fault diagnosis by shown in the table 1 below by comparing the accuracy, this method accuracy is significantly higher than the literature [12], and it has the following advantages: (1) the method first provided by this paper can quickly locate sending channel failure receiving channel fault or orbit, and the accuracy is 100% better than in the table below the accuracy in failure of transmitter and receiver, and a more comprehensive consideration of rail failure can help the staff quickly locate fault zone (2) based on the three types of fault on the basis of accurate judgement, can distinguish each for a total of 21 kinds of failure of concrete failure parts, and the accuracy is higher, the minimum is 90.1%, the highest 100% delimit fault type is more meticulous, can further provide maintenance for maintenance personnel, to speed up the maintenance efficiency, improve the reliability of track circuit operation.

| The fault name                                      | accuracy |
|-----------------------------------------------------|----------|
| Transmitter fault                                  | 96.42%   |
| The cable at the sending end simulates network disk failure | 93.75%   |
| Sending end SPT digital signal cable                | 92.86%   |
| Small track section fault at sending end            | 82.76%   |
| Receiver failure                                   | 93.33%   |
| The receiver cable simulates network disk failure   | 84%      |
| Receiver SPT digital signal cable                   | 91.66%   |
| Failure of small track section at receiving end     | 83.33%   |

In conclusion, the track circuit fault diagnosis method based on convolutional neural network has high diagnostic accuracy and is feasible.

5. Conclusions

In the study of track circuit fault diagnosis, in view of the special circumstances without outdoor equipment monitoring, first by design of orthogonal experiment, obtain comprehensive failure data, aiming at the problem of fault type is more, the first is divided into three types of fault, then give way to small kind of fault, the processed data to construct neural network and experimental comparison, find the parameter combination of high accuracy And the failure data for testing, testing accuracy is higher, when fault occurs, can first quickly locate fault location and accuracy can reach 100%, after the judge fault type, specific minimum accuracy is 90.1%, the highest of 100% even in the absence of outdoor equipment monitoring, still can provide guidance for field maintenance personnel, reduce maintenance time, improve the reliability of signal system, therefore, track circuit based on convolution neural network fault diagnosis effect is good, has practical application value.
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