Optimization Design and Implementation of Intelligent Diagnosis System for AFC Equipment Fault Detection

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Abstract. In view of the problems faced by the operation and maintenance of subway AFC system, such as the distribution of stations, the large number of equipment repairs and the difficulty of fault analysis and diagnosis. On the basis of the research and analysis, taking the operation and maintenance services as the main line, taking the parameters such as influencing the service life and maintenance cycle of the main equipment components of AFC as the characteristic data, and based on the optimization model of the combination of BP neural network and genetic algorithm. After simulation verification, an intelligent fault detection diagnosis system is designed and implemented. It has high application value in system optimization design, equipment physical quantity characteristic detection and intelligent diagnosis, and also has a certain reference guidance role in other design of preventive operation and maintenance systems related to equipment failure.

Introduction

With the rapid development of intelligent cities in China and the sharp increase in the number of urbanized population, rail transit plays an increasingly prominent role in its transportation system. The wide application of the most intelligent automatic ticket selling and checking system (AFC system, Automatic Fare Collection system) is already providing strong scientific and technological support for people to travel conveniently and to improve the efficiency of operation and management and the level of service quality.

The metro is the main part of the urban rail transit system. The current construction and operation of the AFC system and its equipment are various, which not only is the operation and maintenance difficult, and the operation and maintenance cost increases with the operation life. In order to ensure the safe and reliable operation of the AFC system, the operation management service needs to be put into a large amount of people's property resources, and the operation and maintenance of the system can be properly formulated to ensure the safe and reliable operation of the AFC system.[1]

At present, most of the AFC systems are operation and maintenance management mode which adopts the traditional periodical maintenance and fault point maintenance. Because the periodic operation and maintenance of the timing is unable to master the wear degree and the fatigue state of the related components in time due to the periodic operation and maintenance of the timing, more “Over repair”, “Delayed repair” and so on, are easy to occur. After the maintenance of the operation and maintenance resources is wasted, the system cannot be operated normally due to the timely repair of the hidden troubles that have been formed. On the other hand, the influence of the existing operation and maintenance methods on the aging degree of the components of the equipment is not fully evaluated (even if the equipment itself has the running statistical function module), it is easy to fail due to the "late repair"[2].

In view of the problems faced by the operation of AFC system, such as large number of equipment and scattered stations, and unable to master the running state of field components at any time by investing a large number of human and property resources, it is imperative to research and develop a kind of AFC equipment detection and diagnosis system with intelligent characteristics, which is supported by advanced technologies such as modern information and communication.
Typical Failure and Analysis of AFC Terminal Equipment

The AFC system is mainly composed of the automatic ticket vending machine (TVM), semi-automatic ticket vending machine (BOM), automatic ticket checking machine (AGM), ticket card inquiry machine (TCM), which is centrally controlled by the computer, and has the functional equipment such as ticket selling, ticket checking, billing, charging, statistics, sorting, traffic management and so on. It is a system that can realize the whole process of automatic operation and management service of ticket sales and inspection in rail transit. As two important terminal equipment, TVM machine and AGM machine have more than 190 kinds of transmission belt involving different brands and specifications of products, and the related faults caused by transmission belt account for 30-35% of the total faults [3].

The main form is that the ticket card lifting mechanism is stuck or the ticket card transmission channel is stuck, so that the ticket card cannot be transferred from the ticket box to the transmission channel, or cannot be transferred from the transmission channel to the read-write area and the ticket-taking area; The main cause of the related failure is caused by the slip of the transmission belt and the stall of the motor. The failure of transmission belt skidding will lead to excessive wear and tear of transmission belt, reduce the service life, and may even fall off or break, resulting in the problem of transmission lag card or stagnation. The main reasons are as follows:

1) The friction between the conveying belt and the roller is reduced due to the abrasion of the roller of the transmission belt.,

2) Due to the long-time friction between the conveying belt and the roller, the ticket card and the upper and lower bonding layer belts in the transmission process, and further, the friction force between the transmission belt and the roller is reduced.

3) The accumulated oil stain exists on the surface layer of the conveying belt or the roller, so that the friction force between the conveying belt and the roller is reduced, and the sliding friction occurs.

4) Due to the aging deformation of the transmission belt, the circumference is increased, and the effective radial pressure cannot be formed between the conveying belt and the roller. The main friction force between the roller and the transmission belt is changed into a sliding friction force by the rolling friction force [4].

The stall fault of the motor is mainly caused by the overload operation of the motor or the failure of the speed control controller. The stall problem will lead to the sharp reduction of the motor speed and even the sharp increase of the motor current, which will damage the input power supply and the main control board of the module. In very few cases, the problem of motor over speed operation will occur, resulting in abnormal wear of transmission belt or fracture of coupling and other mechanical parts, but the probability of occurrence is low.

Overall Design of Intelligent Diagnosis System for Fault Detection

Brief Introduction to the System Design. Based on the research and analysis of the task content and process of operation and maintenance, with the maintenance business as the core and the intelligent diagnosis of equipment detection as the focus, the overall design of the system is carried out. The main functions of the system are as follows:

1) The Data Acquisition Function of the System Running Equipment. Mainly complete the equipment running status, environment and other data collection, and upload it to the background server database.

2) The Processing Function of the Acquisition Data System. It mainly completes the tasks of parsing, classification and pre-processing of the data received in the background.

3) Fault Detection and Intelligent Diagnosis Function. It mainly realizes the visual display of equipment data, including equipment maintenance analysis and prediction, running state evaluation, fault diagnosis results and so on. At the same time, it can provide all kinds of reports needed for operation and maintenance management.
4) **System Data Management and Maintenance Functions.** It is mainly responsible for the security management and maintenance of background database, including system parameter configuration, system log security and storage management.

The background of the system is Windows or compatible with Linux operating system, developed by C/S architecture, MySQL 5.7 database and JAVA language. And the data acquisition can be realized by using APP loaded by mobile phone terminal equipment through the data processing module built by Web Service.

In addition to fully considering the practical requirements of easy deployment, high reliability, easy operation and maintenance, the overall design also takes into account the reliability of the stable operation of the system, the security of information and the portability of the system. For example, aiming at the access between the system and the AFC system, there will be some network security risks and data security problems. By adding the security isolation gate, the overall security of the system will be improved.

**Design for Data Structure.** In this paper, the data structure design related to intelligent diagnosis, such as TVM computer, including feature information, feature data information table and diagnosis information table structure design, is given. The structure of the feature information table, such as Table 1, is used to describe the collected feature information. The structure of the feature data information table is shown in Table 2, which is used to record the collected eigenvalue data. The diagnostic information table structure in Table 3 is used to record the results of eigenvalue diagnosis of neural network modules.

| Domain Name  | Data Type  | Assigned | Remarks   |
|-------------|------------|----------|-----------|
| ID          | Int        | no       | ID        |
| Name        | Varchar(32)| no       | Feature Name |
| Unit        | Varchar(255)| no     | Eigenvalue unit |
| ModuleTypeID | Int      | no       | Module type ID |
| Recordstatus | Int      | no       | Record status |
| Desc        | Varchar(255)| yes      | Remarks    |

| Domain Name  | Data Type  | Assigned | Remarks   |
|-------------|------------|----------|-----------|
| ID          | Int        | no       | ID        |
| FeatureID   | Int        | no       | Feature ID |
| ModuleID    | Int        | no       | Module ID |
| Value       | Int        | no       | Feature Value |
| CollectDate | DateTime   | no       | Collect Time |

| Domain Name  | Data Type  | Assigned | Remarks   |
|-------------|------------|----------|-----------|
| ID          | Int        | no       | ID        |
| ModuleID    | Int        | no       | Module ID |
| Result      | Varchar(255)| no     | algorithm result |
| Reason      | Varchar(255)| no     | failure cause |
| Advice      | Varchar(255)| no     | Handling suggestion |
| CollectDate | DateTime   | no       | Acquisition time point |

**The Function Design and Implementation of the Intelligent Diagnostic System**

The system function is the technical core of the application development. The intelligent diagnosis is based on the genetic algorithm optimization design of the BP neural network,. The state information of the running equipment such as the TVM, the AGM, the BOM and the server is detected by the intelligent analysis, and the equipment fault diagnosis or pre-judgment is carried out,. Then, the detection and evaluation and the fault diagnosis of the running equipment are realized in the form of a visual graphic and a graph.
Optimization Design of Genetic Algorithm Based on BP Neural Network. The BP neural network is a multi-layer feedforward network with an error correction algorithm, which is widely used in the fields of expert system, pattern recognition, intelligent diagnosis and prediction evaluation because of the ability to solve complex problems. The genetic algorithm has the advantages of strong global cable ability, fast convergence speed and high cable efficiency, and can effectively solve the problem of slow training convergence in the application of traditional BP neural network \cite{5}. In this paper, the genetic algorithm optimization scheme based on BP neural network is designed by using the method of complementary advantages \cite{8}. The technical problems such as optimizing the initial weight and threshold of BP neural network, improving the topological structure of learning network and using genetic algorithm to improve the learning rules of the network are fully considered.

In order to improve the efficiency of genetic algorithm, it is necessary to adjust the population size, selection probability, mutation probability and other parameters according to the problem, so that the algorithm can find the optimal solution quickly. The following six parameters are mainly considered for adjustment.

1) Coding length. According to the problem to be solved, the longer the coding length of binary coding gene is, the higher the accuracy is and the larger the operation time is.□

2) Population size. The number of individuals in the initial population is called the size of the population. The more the number of individuals is, the higher the diversity of the population is, and the better the search ability of the algorithm is. However, too many individuals will increase the amount of computation and reduce the speed of learning search, while too few individuals can reduce the search time, which can easily lead to the premature convergence of the algorithm. Generally, it is appropriate to select the initial population in the range of 20-100.

3) Selection probability. The genetic algorithm uses the fitness value to select the individual, and the selection probability determines the possibility that the individual will be retained. Usually, the greater the probability of selection, the more likely the individual is to be retained, and vice versa.

4) Cross probability. Genetic algorithms can generate new individuals by crossing, and the probability of crossing determines the possibility of generation. If the cross probability is too small, it will affect the genetic diversity; if the cross probability is too large, it will cause the loss of excellent individuals. Usually, the most suitable cross probability selection range is 0.4-0.9.

5) Probability of variation. Used to select new individuals that can be produced in a way that mutates. The probability of general variation is between 0.0001 and 0.1; if the selection is too large, the original attribute of the individual will be destroyed, and the algorithm will lose the search capability.

6) Cut-off algebra. Using cut-off algebra as a condition for the algorithm to end the search. normally, the selection range is between 10 and 1000.

The Construction and Simulation of the BP Neural Network Model. For the construction and simulation of the mode \cite{6}, the typical faults of TVM machine, which directly affect the service quality of passenger ticket purchase, are briefly described.

**Determine fault features and input and output values.** The input and output values is shown in Table 4, such as 1 ( belt aging ) in typical fault analysis, 2 (belt wear) , 3 (motor overload) and 4 (normal condition).

| No. | Input Parameter                  | No. | Output Result     | Code  |
|-----|---------------------------------|-----|-------------------|-------|
| a   | Belt A length(mm)               | 1   | Belt aging        | 0100  |
| b   | Belt B length(mm)               | 2   | Belt wear         | 0010  |
| c   | Belt C length(mm)               | 3   | Motor overload    | 0001  |
| d   | Belt D length(mm)               | 4   | Normal condition  | 1000  |
| e   | Belt E length(mm)               |     |                   |       |
| f   | Card issuing motor A speed/(r/min) |     |                   |       |
| g   | Card issuing motor B speed/(r/min) |     |                   |       |
| h   | Motor speed of temporary storage area (r/min) |     |                   |       |
| i   | Number of used belt (10,000 times) |     |                   |       |

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Select the training data. The representative 1000-group data is selected from the data processing, of which 900 groups are used as training sets, and 100 groups are used as test sets; the selected typical training set data is shown in Table 5.

| No. | Input1 | Input2 | Input3 | Input4 | Input5 | Input6 | Input7 | Input8 | Input9 | desired output |
|-----|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------------|
| 1   | 183    | 238    | 247    | 428    | 456    | 1000   | 925    | 1922   | 15.3   | 0100          |
| 2   | 172    | 239    | 247    | 428    | 456    | 1001   | 925    | 1930   | 15.1   | 0010          |
| 3   | 173    | 239    | 247    | 428    | 457    | 1001   | 925    | 1921   | 16.1   | 0001          |
| 4   | 167    | 233    | 241    | 422    | 457    | 1000   | 925    | 1920   | 15.0   | 1000          |

The parameters of BP neural network structure are designed. A three-layer neural network structure is adopted, in which the number of nodes in the hidden layer is selected with reference to the following formula:

\[ l < n - 1 \]  \hspace{2cm} (1)

\[ l < \sqrt{(m+n) + a} \]  \hspace{2cm} (2)

\[ l = \log_2 n \]  \hspace{2cm} (3)

In the formula, \( n \) is the number of nodes in the input layer, \( l \) is the number of nodes in the hidden layer, \( m \) is the number of nodes in the output layer, and \( a \) is a constant between 0 and 10.

The design of a three-layer neural network structure shows that the number of input layer nodes is 9, the number of output layer nodes is 4, and the network accuracy is set to 0.001. After testing the number of all possible hidden nodes with 3 to 9 hidden nodes, the statistical results show that when the number of hidden nodes is 6, the training error is small and the number of training steps is also small. Therefore, the number of hidden layer nodes is set to 6, the transfer function between the input layer and the hidden layer is S-type function, and the transfer function between the hidden layer and the output layer is a linear function.

Matlab program simulation experiment results. The design model is simulated by the Matlab program. The parameters of the BP network topology are 9, 6 and 4 as described above. The maximum training frequency is set to 100000, the convergence precision is set to 0.001, and the learning rate is set to 0.01. It can meet the accuracy requirements at step 13987 with a mean square error of 0.000734374.

For 100 sets of test data, the absolute error is taken as the absolute value of the actual output and prediction of the test sample. According to the test results of the sample and the actual situation of the equipment, it is considered that the diagnostic error will occur when the absolute error is more than 0.5. Through the test of 100 groups of test samples, the absolute error of two groups is more than 0.5, which shows that the recognition accuracy can reach 98%, which indicates that the design model has good feasibility and applicability.

**Optimal Design and Simulation of BP Neural Network Based on Genetic Algorithm**

1) The parameter selection and setting of the optimized design. The topological structure of the BP neural network is 9-6-4, the final initial weight and the total number of the H-layer BP neural network are 88 (9 * 6 + 6 * 4 + 6 + 4), that is, the total of 88 data needs to be optimized, and the code chain length is 88. The chromosome contains 88 genes. When the number of the initial population is determined, the code chain of length 88 is automatically generated, and the generation range of the data is selected as (-3, 3). For the initial population number, the training error and step size result obtained by many experiments, the training error of the system is the smallest when the initial population number is 40. Therefore, the optimal parameters of genetic algorithm are determined as...
follows: population size is 40, cross probability is 0.3, mutation probability is 0.1, and the maximum number of iterations is 100. The optimal individual is optimized by genetic algorithm, and the decoded weight and width are used as the initial weight and min value of BP neural network.

2) System simulation of optimal design. The same as the above experimental environment, in matlab environment, the same 10000 sets of sample data are used to optimize the training of BP neural network based on genetic algorithm. the training error curve is shown in figure 1. When the step reaches 1641, the mean square error is 0.00053683. Re-selected 100 sets of data as samples for simulation testing, there is 1 set of absolute error more than 0.5(see figure 2, that is, the identification error rate is 1%.

![Figure 1. Matlab simulation results that Genetic algorithm optimizes BP neural network.](image1)

![Figure 2. Absolute error of Matlab simulation of BP neural network.](image2)

3) The simulation results are compared and analyzed. The simulation results of GA-BP neural network and BP neural network optimized by genetic algorithm are compared and analyzed. The simulation results of GA-BP and BP neural network optimized by genetic algorithm show that the sample training error of GA-BP network can meet the requirements of the set expected value and error accuracy; The network training can reach 1641 steps to converge, the mean square error is 0.053797621, and the error can be reduced by 26.8%, and the convergence speed can be increased by 2.53%. Through the simulation test of 100 groups of samples, the correct rate of fault diagnosis can be improved by 1% to 99%, which can meet the demand of intelligent diagnosis of equipment fault.

Realization of the Function of Intelligent Detection and Diagnosis System

On the basis of completing the simulation experiment of the overall design of the system and the optimal design of the intelligent detection and diagnosis, the function of the system is developed and realized. Fig. 3 shows the number of faults in AFC equipment of metro stations obtained by statistical
analysis of the system. The trial operation shows that the system is stable and reliable, the detection data is accurate, and the correct rate of equipment fault diagnosis is more than 98%. It can meet the needs of AFC system equipment detection and maintenance business, and achieve the goal of increasing management efficiency and reducing operation and maintenance costs.

Figure 3. Chart of TVM faults with intelligent diagnosis in metro AFC system.

Conclusion

Based on the research and analysis of typical equipment and fault form of AFC system, an intelligent fault diagnosis system for AFC equipment is designed and implemented based on BP neural network and genetic algorithm optimization model. The results of system modeling, simulation and practical application show that the system is reasonable in design and advanced in technology. It has high application reference value in BP neural network optimization design, equipment physical quantity characteristic detection and intelligent diagnosis, and also has certain guidance for the design of preventive system operation and maintenance system related to equipment failure.

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