Error Analysis and Fault Diagnosis of CNC Machine Tools under Artificial Intelligence Technology

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Abstract. With the development of technology and the arrival of the era of artificial intelligence, the relationship between machine and human is becoming closer and closer. This paper mainly studies the error analysis and fault diagnosis of CNC machine tools based on artificial intelligence technology. The detection of machine tool error is mainly completed by laser interferometer. In this paper, a dual frequency laser interferometer is used. In order to ensure the efficiency of the program, the display image is refreshed in 20ms. According to the structure analysis, the error branches of CNC machine tools are determined, and the position feature relationship and motion feature relationship between adjacent bodies in each error branch are analyzed. In this paper, the fault tree analysis method is used to establish the fault tree model of computerized numerical control machine tool, and the fault reasoning method based on fault tree is given. On this basis, the deep neural network model is used to classify and identify the difficult to identify features such as fault degree, so as to achieve the purpose of deep fault diagnosis. The data show that the average recognition rate of BP network before feature reduction is 82%, and the average recognition rate of BP network after feature reduction is 86%. The results show that artificial intelligence technology can improve the accuracy of error analysis of CNC machine tools.

Keywords: Artificial Intelligence Technology, CNC Machine Tools, Error Analysis, Fault Diagnosis

1. Introduction
With the increasing share of CNC machine tools in the machine tool industry, it is more and more urgent for the society to master the high skilled talents of CNC machine tool maintenance. At present, most of the enterprises using CNC machine tools are in the mechanical processing industry, and the technicians in the mechanical processing industry are generally very weak in electrical knowledge, they only know how to operate and program, but lack of supporting maintenance knowledge.

At present, CNC machine tools in enterprises are generally repaired by technicians of CNC machine tool manufacturers. However, due to the delay of maintenance technicians on the way to the maintenance site, the starting rate of CNC machine tools will be reduced, causing certain economic...
losses to enterprises [1-2]. With the increasing complexity of mechanical equipment, the fault information will be complicated and bring the rapid expansion of information resources [3]. At the same time, the economic development requires to greatly improve the timeliness and accuracy of fault diagnosis [4]. In the production process of finished products, the possible states or faults of CNC machine tools are ever-changing. Simply recording and tracking the state or fault types of machine tools can not achieve the reuse and sharing of diagnosis experience [5-6]. Even if the enterprise has a perfect learning and communication mechanism, it is difficult to adapt to the current large-scale and cross regional production environment [7]. Because the following error is the characteristic of CNC system, it can't be eliminated completely. It can only be adjusted to reduce the error, but can't be eliminated fundamentally [8], so it's necessary to analyze it, determine the contour error caused by the following error, predict the error, and put forward the corresponding countermeasures to reduce or eliminate the contour error [9-10].

Artificial intelligence has the functions of perceiving environment, detecting mode, understanding and decision-making. Mobile Internet and other development dividends are gradually disappearing. A new round of product change makes artificial intelligence the core direction of industrial change. The era of artificial intelligence has come and penetrated into all fields of social life. With the rapid development of software application and the increasingly mature Internet technology, the development obstacles of network transmission speed and network instrument application have been eliminated, which makes it possible to build a developmental, modular and scalable network measurement and control system.

2. Error Detection and Fault Diagnosis

2.1 Artificial Intelligence Technology

In order for artificial intelligence to have feelings and "emotions", it is necessary to study the principles of emotion generation. First of all, it is important to understand the causes of emotion and reasoning. The internal logic program of emotional operation is not equivalent to the change data of various physiological indicators when people are performing emotional reactions. Emotional responses may be caused by external stimuli captured by our senses, by internal stimuli with changes in homeostasis, or by our own cognition. The processing of stimuli produces changes at the unconscious level of the physical state.

2.2 Error Analysis and Fault Diagnosis of CNC Machine Tools

For non-stationary vibration signal processing, it is difficult to obtain stable periodic signal only from time domain or frequency domain processing, and wavelet transform has strong time-frequency processing ability for non-stationary impact signal, so it is feasible to apply wavelet transform to process spindle vibration signal to obtain spindle rotation error signal. The basic wavelet function is $\psi(t)$, let:

$$Wf(a,b) = \frac{1}{\sqrt{a}} \int f(t)\psi^*\left(\frac{t-b}{a}\right)dt$$  \hspace{1cm} (1)

The wavelet packet function of orthogonal wavelet packet transform is as follows:

$$\begin{cases} 
\phi(t) = \sqrt{2} \sum_{k \in Z} h_k \phi(2t-k) \\
\psi(t) = \sqrt{2} \sum_{k \in Z} g_k \phi(2t-k) 
\end{cases}$$  \hspace{1cm} (2)

The margin coefficient is mainly used to reflect the impact strength, and it is more sensitive to the impact fault of the bearing. Its expression is as follows:

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\[ L = \frac{X_p}{X_r} = \frac{X_p}{\left( \frac{1}{N} \sum_{i=1}^{N} \sqrt{|x_i|} \right)^2} \]  

The fault tree analysis method has high reliability and safety, it is to build a logic diagram of various potential factors of equipment failure, starting from a specific fault event, starting from a point of divergence analysis, judging along each branch of the tree, in order to find the final cause. In order to effectively prevent monitoring and eliminate relevant faults in time, we need to rely on the data acquisition system to collect data in the key parts of the CNC machine tool, and then analyze the data parameters, and finally determine the fault location and cause.

3. Error Detection Experiment of CNC Machine Tool

3.1 Experimental Environment
The detection of machine tool error is mainly completed by laser interferometer. In this paper, a dual frequency laser interferometer is used. The specific parameters are shown in Table 1. The number of radial error data in the data document is the data sampling points of the acquisition system from the beginning to the end of the machine running.

| Performance                          | Parameter  |
|--------------------------------------|------------|
| Linear measurement accuracy of full stroke | ±0.5ppm    |
| Linear resolution                    | 1nm        |
| Maximum measuring speed              | 4m/s       |
| Automatic update interval of environmental compensation | 7s         |
| Dynamic sampling rate                | 50kHz      |
| Standard measuring stroke            | 80m        |

3.2 Error Detection
According to the structural analysis, the error branch of the CNC machine tool is determined, and the position characteristic relationship and movement characteristic relationship between adjacent bodies in each error branch are analyzed.

3.3 Fault Diagnosis
In this paper, the fault tree analysis method is used to establish the fault tree model of computerized numerical control machine tool, and the fault reasoning method based on fault tree is given.

4. Discussion

4.1 Error Results
A total of 75 groups of 25 samples of each type of data were processed by mean subtraction and normalization, and then each signal was EMD decomposed to calculate the above 6 time-domain eigenvalues of the first three IMF components and the Fi value of each group of data. The 19 parameters of each sample were used as the input of the model to train the network model. The iterative process of determining the number of hidden layer nodes is shown in Figure 1. Each parameter combination will lead to different classification results. In other words, different parameter combinations will lead to different classification effects. The lower the entropy of classification information, the better the classification effect will be. When the number of memory antibodies is 5, the classification effect is the best. The classification entropy PE and the classification overlap coefficient PC reach the minimum value of 0.14 and the maximum value of 1.45 respectively. It can be seen from the training process that in the case of the same target error, the artificial immune
network and BP artificial neural network are trained with the same sample training. The BP network training needs 137 generations, while the artificial immune network training only needs 26 generations, which greatly improves the learning efficiency. The final training error of BP network was 0.0098236, while the final training error of immune network was 0.00121727, which improved the network performance. The existence of redundant information will complicate the rolling bearing fault diagnosis system model, reduce the diagnosis efficiency of the system, and even affect the accuracy of the diagnosis results. Therefore, after the original fault signal is extracted, the eigenvalues are often screened and simplified to screen out the eigenvalues that have a greater impact on the diagnosis results, so as to simplify the diagnosis system model and improve the efficiency and accuracy of fault diagnosis.

![Figure 1. The iterative process of determining the number of hidden layer nodes](image1)

Figure 1. The iterative process of determining the number of hidden layer nodes

The comparison of different feature classification capabilities is shown in Figure 2. The average recognition rate of BP network before feature reduction is 82%, and the average recognition rate of BP network after feature reduction is 86%. The recognition rate of BP network established after feature reduction is 4% higher than before reduction, and the number of training steps is reduced by more than half. Through feature reduction, while ensuring the recognition rate, it simplifies the network structure and shortens the training time, which shows that through the correlation analysis between features and fuzzy clustering, sensitive features can be retained and redundant features can be deleted. Through the above analysis, the diagnostic accuracy of the classifier can be regarded as the description of the uncertainty in the judgment of the fault type, and it can be quantitatively evaluated with the concept of information entropy. The smaller the information entropy, the smaller the uncertainty of the result of the classifier, and the higher the reliability, the higher the accuracy of the classifier's diagnosis. The greater the information entropy, the greater the uncertainty of the result of the classifier, the lower the reliability, and the lower the diagnostic accuracy of the classifier. It can be seen that the local wave decomposition method effectively extracts the fault characteristics from the instantaneous non-stationary signal. Compared with the traditional method, it can judge the failure of various components more effectively. It can decompose the weak fault characteristics under complex conditions. It is suitable for engineering applications. The fault diagnosis of CNC machine tools is of great significance. For the linear model, the prediction performance of V-MRA and PLSR method is better than that of D-MRA method, which indicates that the collinearity of temperature has a certain influence on the accuracy of model establishment, and variable selection and partial least squares regression method can help to reduce this influence. The comparison of V-MRA and PLSR method shows that although the fitting performance of PLSR method is not as good as that of V-MRA method, the prediction performance of PLSR method is better than that of V-MRA method. In the prediction, the performance of PLSR and V-MRA is similar or even slightly better, which indicates that the removal of the lead screw, an important temperature variable in variable selection, has a certain impact on the prediction accuracy of the model.
4.2 Fault Diagnosis Analysis

The number of sampling points is 8192, and the sampling frequency is 10kh. Three typical fault characteristic frequencies of the rolling bearing and the harmonic frequencies at the second and third harmonic frequencies are calculated by using the above formula. The calculation results are shown in Table 2. In different feed speeds, the positioning error is discrete point, and it is concluded that the feed system and servo system of the CNC machine tool are good, and the feed speed has no obvious effect on the positioning error; the positioning error increases with the increase of displacement. The experimental results show that when the feed rate is lower than 1000mm / min, the feed rate has little effect on the positioning accuracy, repeat positioning accuracy and reverse clearance compensation accuracy; when the feed rate is higher than 1000mm / min, the higher the feed rate is, the lower the positioning accuracy, repeat positioning accuracy and reverse clearance compensation accuracy are; when the closed-loop gain KF of the CNC system is equal, the higher the feed rate is, the lower the positioning accuracy, repeat positioning accuracy and reverse clearance compensation accuracy are; when the closed-loop gains are not the same, with the increase of the difference between these gains, the accuracy of positioning and repeat positioning and the accuracy of reverse clearance compensation are decreasing. This is especially true at higher feed rates. In order to compensate the straightness error skillfully, it is necessary to carry out coincidence on the error measurement value to eliminate the angle error. The results show that the compensation effect of straightness error with angle error is worse than that of straightness error without angle error. In the experiment of position deviation compensation in rotation, the ball bar instrument is used as the test tool, and the method of dynamic motion chain parameters compensation is adopted, and the effect is remarkable.

Table 2. Experimental results

| Fault type       | First harmonic (Hz) | Second harmonic (Hz) | Third harmonic (Hz) |
|------------------|---------------------|----------------------|---------------------|
| Outer ring failure | 57.2                | 114.4                | 171.6               |
| Rolling element failure | 73.5                | 147                  | 220.5               |
| Inner ring failure          | 89.5                | 179                  | 268.5               |

5. Conclusions

In this paper, based on the analysis of the types and causes of machine tool error, the error modeling method based on multi-body dynamics theory is used to build a comprehensive model, and the actual measurement of the accuracy data of the machine tool is used for error analysis and compensation.

According to the dynamic characteristics of the spindle system, the working state of the spindle system of CNC machine tools is monitored in real time, and its deterioration and reliability are analyzed, which provides basic data for improving the stability of the whole system and the deterioration trend of the spindle system.
For the medium precision machine tool, the main error is the geometric error of the machine tool, and one of the geometric errors occupies the main position, so the single error compensation does not mean that all the single errors are compensated at the same time.

Acknowledgments
This research is supported by the Provincial (Key) Natural Science Research Project of Anhui Colleges (KJ2019A0844), Domestic visiting research projects for excellent young backbone teachers of Anhui Colleges (gxgnfx2020116)

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