Research on Intelligent Monitoring Technology of Micro Hole Drilling

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***Abstract*—Aiming at the problem that the micro drills is easy to be broken in the process of drilling; it is difficult to detect the drill bit. The drilling torque signal is taken as the monitoring object. A new method for the on-line monitoring the micro-drill breakage based on BP neural network is proposed. After the three layer wavelet decomposition of the drilling torque signal, the energy feature vector is used as the input layer of the BP network, and the mapping model of the working state and the drilling force of the micro drill bit is obtained by using the network structure of the four layers. Using MATLAB software and Lab VIEW software, a micro drill on-line monitoring software system is constructed. The experimental results show that the accuracy of the wavelet neural network is very high, which is more than 90%, which shows the validity of the monitoring model and the popularization of the system.**

Keywords-Micro-role drilling; Micro-drill; Wavelet neural network; On-Line monitoring; Force

I. INTRODUCTION

Along with the development of technology at very fast speed, the micro-roles' application is tend to become more and more extensive[1]. The most practicable method among all drilling methods is still power drilling by the micro twist drills. During micro-role drilling ,the drill is subject to breaking, and the part containing broken drill will be scraped, therefore how to avoid micro-drill breakage has been a difficult technical problem[2-5]. Essential cause to drill breakage is that the drilling torque increases along with drill wear process and finally exceeds strength limit of the drill[6]. If the drilling torque can be predicted and the warning can be given on-line by drilling torque monitoring, micro-drill breakage will be avoided effectively.

Wavelet neural network is combining wavelet theory and neural network, which has the high auto-adapt character and robustness character[7].This paper carried out their nonlinearity mapping both micro-drill breakage and breakage signals based on BP neural network, whose input signal was the energy eigenvectors of torque by using wavelet packet transform. Furthermore, a kind of software system to on-line monitoring micro-role drilling has been constructed by using Matlab software and LabView software.

II. WAVELET NEURAL NETWORK

A. Wavelet and Wavelet Analysis

Wavelet is a kind of wave with finite length and zero-average value. The low frequency part of signal may be decomposed and analyzed by Wavelet analysis which came from signal analysis and the flex, parallel shift characters of the function. Wavelet packet analysis may process effectively decomposing to all frequency range signal, and be propitious to distill the characteristic of signal[8].

If $\varphi(t) \in L^2(R)$,it's fourier transform satisfies the following admissible conditions:

$$C_\varphi = \int_{-\infty}^{+\infty} \frac{|\hat{\varphi}(\omega)|^2}{\omega} d\omega < \infty \qquad (1)$$

$\varphi(t)$ is the basic wavelet or wavelet generating function. Continuous wavelet transform is defined as

$$\varphi_{a,b}(t) = \frac{1}{\sqrt{a}} \varphi\left(\frac{t-b}{a}\right) \qquad (2)$$

$$(WT_f)(a,b) = |a|^{-1/2} \int_R f(t) \overline{\varphi(\frac{t-b}{a})} dt \qquad (3)$$

$f(t) \in L^2(R)$ （$a, b \in R \ \ a > 0$）[8].

B. BP Neural Network

The structure of the BP network is shown in Fig.1. The network includes the input layer, hidden layer and output layer, the hidden layer can is composed of multiple layers, each layer has a plurality of nodes, front layer and a rear layer by weight connection, no coupling between nodes on the same layer[9].

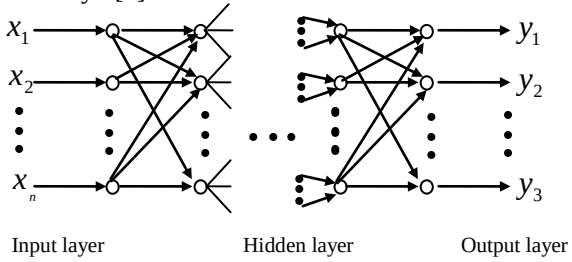


Figure 1. Neural network structure

BP neural network, as well as neural network whose error is transmitted in reverse, which has many layers framework, including input layer, output layer and some crytic layers. Its training steps are that the first step is to pick up a training sample among the muster and input to the neural network; the second step is to calculate network's output; the three step is to calculate the error between its input and its output ; next step is to adjust the network value in order to minish the error form output layer to former layers. Each training sample is trained by the method until the network's error becomes minimum[10].

C. *Wavelet Neural Network*

Wavelet neural network is relax combining wavelet analysis and neural network. It utilizes the local characteristic and the powerful distilling speciality of wavelet analysis or wavelet packet analysis which is used to be the label processor of neural network in time domain and frequency domain to decompose the signal to some independent frequency range. A new vector is given birth to be input signal to neural network, which is composed by all energy values in all frequency range. Applying those methods to construct wavelet neural network will make network structure more simple and comprehensible. And at the same time, network training time will be shortened and learning efficiency of network will be enhanced.

The flowchart of wavelet neural network is shown in Fig.2.

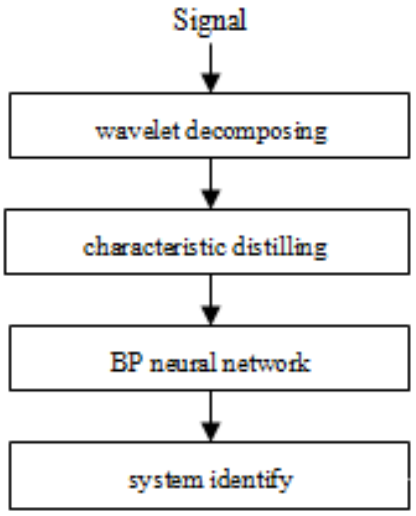


Figure 2. Flowchart of wavelet neural network

III. ON-LINE MONITORING EXPERIMENT SYSTEM DESIGN

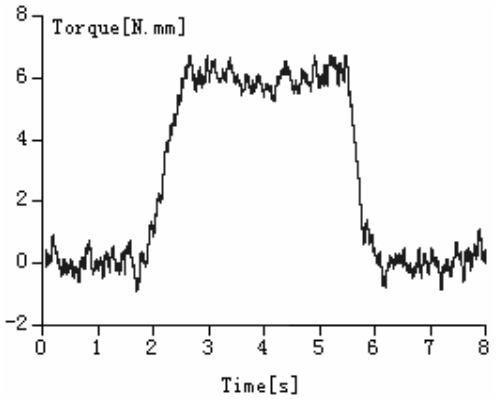
A. *System Model*

Experiment indicated that essential cause to micro-drill breakage is that the drilling torque increases and finally exceeds strength limit of the drill. the torque signals both in fine condition and in breakage condition shown as Fig .3 were set up.

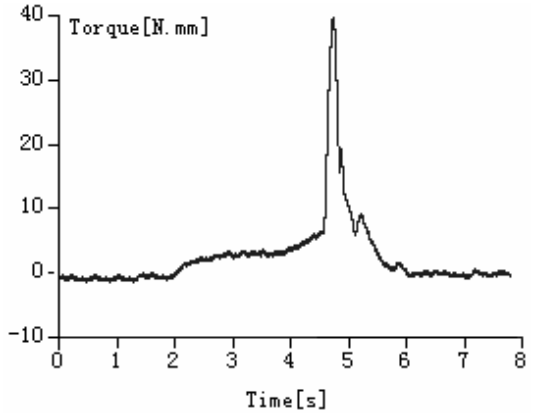
In this paper, the drilling torque signal is monitored and decomposed into three layers wavelet packet(shown as Fig .4), x_{ij} is the amplitude of the reconstruct signal, and E_{3i} is the energy signal of the third layer wavelet packet, whose calculating function is,

$$E_{3i} = \int |S_{3i}(t)|^2 dt = \sum_{j=1}^{N} |x_{ij}|^2 \quad (4)$$

Where, N is the data number; i is the sequence number, i=0 to 7.



a. fine condition



b. breakage condition

Figure 3. Torque signals of micro-drill

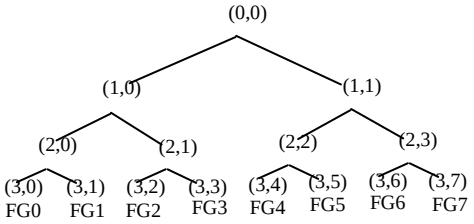


Figure 4. Three layers wavelet decompose tree

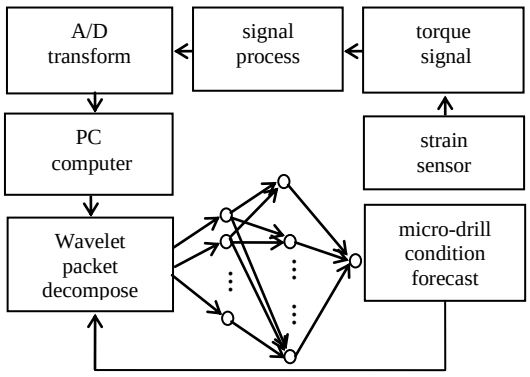


Figure 5. wavelet network monitoring model

The energy signal decomposed is input to three layers neural network for network training and learning, A mapped between energy variety and micro-drill breakage is built up, at last the monitoring liminal value may be calculated.

The experiment was carried out with a CNC precision micro-size drilling machine. For on-line monitoring drilling torque, total neural network system is shown as Fig .5. In the system, the data of drilling torque signal were collected by strain sensor, then it was transmitted to the industrial PC though NI6013 data acquisition board (16-bit resolution and 200 kHz sample frequency), and were processed in there by BP neural network in this paper. The network gave the judging result about micro-drill condition. In the experiment, the spindle rotating speed was 15000r/min; the feeding speed was 40mm/min. The workpiece material was stainless steal with 1.5mm thickness. The drill diameter was 0.4mm.

B. Network Training and Learning

This network has 8 input nodes and 1output node which judges micro-drill fine or breakage and 15 middle nodes calculated in the light of (2*n-1)principle[9](where, n is input nodes).The paper assumed that system error was 0.001, learning rate was 0.8, momentum gene was 0.7, maximum training time was 2000.

Under the experiment condition described above, drilling experiments were carried out. Then take that 50samples, including 40 training samples and 10 testing samples to train wavelet neural network, obtain network output corresponding to each sample.

After 326 times of training, the network converges to the precision requirement. After network training, degree of the network training results and comparison of micro drill actual cutting conditions, the comparison figure between the network output and the target network training was plotted as shown in Fig. 6. When the microdrill is in normal state, the expected output of the network is 0.1, while that of the breakage is 0.9. The results show that the output of the wavelet neural network can correctly reflect the cutting state of micro drills. The network has achieved good performance requirements.

Table1 is testing result.'+' showed testing true or '-'showed testing fault. Result made clear that true testing rate to checking out micro-drill breakage has attained 90%,the on-line monitoring system was proved efficiently.

TABLE I. DATASHEET TO NETWORK TESTING

No.	Input layer nodes data of BP neural network								Network output	Drills condition	Test result
	FG0	***FG1***	***FG2***	***FG3***	***FG4***	***FG5***	***FG6***	***FG7***			
1	11.62	19.27	26.52	179.8	375.2	725.5	1431	51.72	0.1098	fine	+
2	147.4	595.1	7581	595.5	166.2	8099	8951	11979	0.8508	breakage	+
3	96.33	408.7	7564	2317	170.6	9351	1655	556.1	0.1013	fine	+
4	149.8	3349	4979	2617	1471	5447	1359	14802	0.8856	breakage	+
5	96.00	1142	3033	798.5	146.5	6949	4607	2980	0.1101	fine	+
6	17.00	28.14	40.45	272.7	606.4	1356	3620	75.57	0.1024	fine	+
7	125.7	9285	17921	6974	1179	9684	6647	11820	0.9756	breakage	+
8	142.3	612.5	1607	850.0	215.4	7940	9133	2768	0.2427	fine	+
9	122.6	2794	6221	1397	1223	8757	4606	17890	0.8257	breakage	+
10	230.0	120.5	1949	3310	6113	3176	7143	1372	0.7283	breakage	-

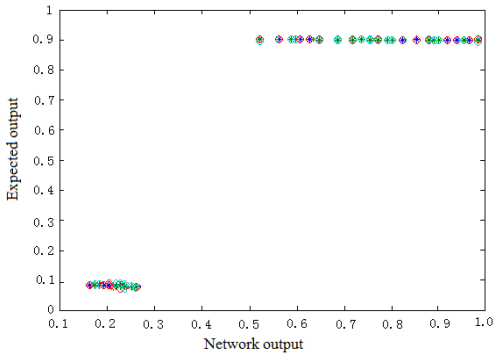


Figure 6. Comparison between target output and simulation results

In this paper, the data will be normalized after the network training, using the normalized equation(5) as follows:

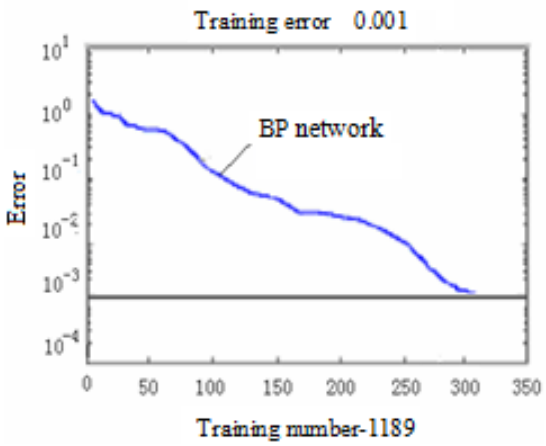
$$x'_j = \frac{0.9-0.1}{x_{j\max} - x_{j\min}}(x_j - x_{j\min}) + 0.1 \qquad (5)$$

$x_{j\max}$、$x_{j\min}$ is the maximum and minimum values of the output characteristic，x'_j is normalized data.

C. *Comparative analysis of wavelet neural network and BP neural network*

The same experimental data are input to the BP neural network and wavelet neural network system for state identification and comparative analysis, as shown in Fig .7.

In order to better the accuracy comparison of two kinds of network, another 35 groups of samples were input to the two neural network model has been trained, then the network output and the actual state of the sample comparison, obtained results contrast Table II shows the. It is clear that the accuracy of the wavelet neural network to the new data is obviously higher than that of the BP network, which shows that the improved neural network has better robustness.



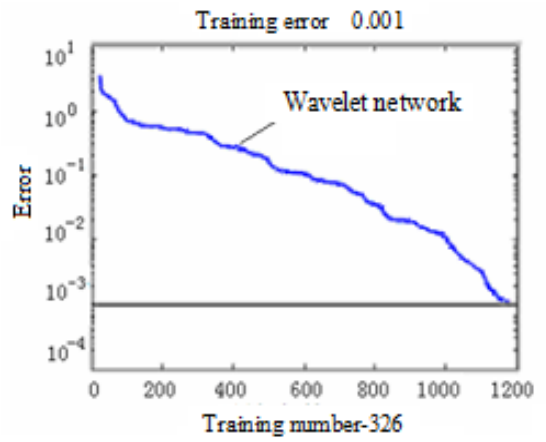


Figure 7. Velocity curves of the two networks drilling

TABLE II. NETWORKS CONTRAST

	normal		breakage		accuracy rate
	train	*test*	*train*	*test*	
BP network	20	15	20	15	87.0%
Wavelet network	20	15	20	15	93.3%

IV. MONITORING EXPERIMENT

According to data in Table I, anther 3 drill groups (10 drills each group) were taken to perform experiments using already trained network. Drills in first group did not employ on-line monitoring while drilling until breaking. Drills in other 2 drill groups were monitored on-line while liminal value was 0.75 for second drill group and 0.55 for third drill group. For each drill in second and third group, keep drilling until warning and drill backing off. Experimental results are shown in Table III.

TABLE III. ON-LINE MONITORING EXPERIMENTAL RESULTS

group No.	average holes drilled	breaking drills
1	49.6	10
2	45.1	1
3	40.7	0

V. CONCLUSION

A. The micro-drill monitoring method based on wavelet neural network is efficient under much model analysis and monitoring experiment.

B. Taking drilling torque as monitoring object and using strain sensor as measuring element are able to well monitoring drill wear states in drilling process. Therefore, it is convenience to use in practice.

C. On-line monitoring effect is relate to liminal value. Using low liminal value has well effect to forecast micro-drill breakage, but drilling role number is few

relatively. liminal value should be set up according to machining condition in practical drilling.

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