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Study and Experimentation on Detection of Nicks inside of Porcelain with Acoustic Emission

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ABSTRACT

An usual acoustic emission (AE) event has two widely characterized parameters in time domain, peak amplitude and event duration. But noise in AE measuring may disturb the signals with its parameters and aggrandize the signal incertitude. Experiment activity of detection of the nick inside of porcelain with AE was made and study on AE signal processing with statistic be presented in this paper in order to pick-up information expected from the signal with noise. Effort is concentrated on developing a novel arithmetic to improve extraction of the characteristic from stochastic signal and to enhance the veracity of detection. The main purpose discussed in this paper is to treat with signals on amplitudes with statistic mutuality and power density spectrum in frequency domain, and farther more to select samples for neural networks training by means of least-squares algorithm between real measuring signal and deterministic signals under laboratory condition. By seeking optimization with the algorithm, the parameters representing characteristic of the porcelain object are selected, while the stochastic interfere be weakened, then study for detection on neural networks is developed based on processing above.

Keywords: Detection, Nick, Porcelain, Acoustic Emission, signal processing, neural networks

1. INTRODUCTION

To finde inferior porcelain product, i.e. nicks inside of porcelain, by traditional method on manual work is to knock the product individually, at the same time to listen the sound of vibration from the objector and analyse the difference about the sound patterns among the memory in mind and select best matching among them, finally to give the judgement. But this manipulation has some limitation because of different experience individually and the sound disturbed from noise. So it is hard to use perfectly, especially on production line.

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In order to identify and classify the quality of porcelain product automatically on line, it is the first step that we should make machine or computer to knocking the product for its to come into being acoustic emission (AE), and then we are able to collect the signals of vibration. The next step, important and complex one is to process the signals from AE the machine gotten and to analyse the characteristic parameter one by one, and then compare difference from each other, finally to give information report of any porcelain to human as a result of working. So the system we have developed and studied is to have the intellective unit to imitate human being operation in listening the sound and analysing the signals automatically.

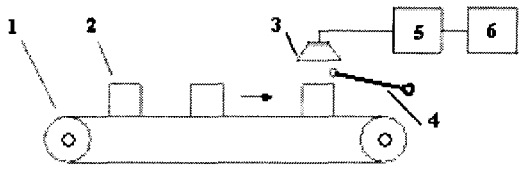
Until now, in signal processing and analysing domain, especially where we can't formulate an algorithmic solution, the artificial neural network (ANN or NN in short) is a very promising one[1,2]. However, vibration or AE signal contains much more noise although including useful information.

If these original signal is directly as input data to give neural networks, the NN structure would become large and complex, its function could not bring into play. This is owing to large useless calculation in NN. In order to solve his problem, the statistical method in time domain and power density spectrum techniques in frequency domain are adopted individually or mutually to help to select the parameters important in characteristic of detection by experimentation, and then to determine the representative parameters through list comparing by experts. The work described above is the important step in signal processing[2], and then it is also the basic of selection for NN training samples[3]. The next important step is to select and train the neural networks.

After learning by the training samples, the neural networks can diagnose porcelain quality with less time, few calculation amount and higher reliability.

2. SYSTEM STRUCTURE DESIGN

The experiment device and system structrure is shown in Fig. 1. When porcelain product is at a specified place, i.e. under the signal collector, we must let the objector come into being acoustic emission (AE) right now, so it is knocked gently by knocking device. Upon that it is to become into vibration and give the AE. To receive the signals, a collector to collect the waveforms of AE has a analog channel with a analog filter, the signals must to pass the channel with the filter to reduce high frequency noise, and then into A/D converter, where the analog data is to be converted into digital data and then be calculated by digital signal processor, including digital filter and digital signal processing. Then the digital parameters of the signal are calculated and made certain as input signal to neural networks. The neural networks, which is inputed with the digital parameters, calculates or determines of the characteristics and outputs re-



1. transportation device 2. porcelain products
3. AE collector 4. a knocking device
5. analog signal collector and processing unit
6. computer

Fig. 1. Experiment device on line of porcelain production.

sult of calculation. At last, the expert system finishes the statistic of qualification rate and gives the report about any inferior product[4,5].

There are two important parts in the experiment devise above, called analog signal collector and processing unit, NO. 5 and digital signal processing unit (i.e.computer and software), NO. 6 in Fig. 1. We call them the processing system. Fig. 2 shows the more detail of the processing system. The structure of the processing system for detection of nicks inside of porcelain with AE is the main work in this paper. In this system, signal (i.e. AE) are collected by the audio collector, so called AE collector. In the pre-processing and A/D unit, the signals are to go through band-pass filter (analog filter), and then converted into digital data by A/D converter. Next step, digital datum are processed by digital processing unit and the unique features of every porcelain products are collected from processed data. After digital processing unit, the characteristic information is taken as character data and as the input of neural networks in intellective system. Finally the porcelain product is identified and the result is reported by intellective system[6].

In the Intellective System, neural networks are designed to identify the state by means of features

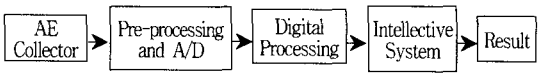


Fig. 2. The structure of the processing system.

from the AE signals. In many features, we should choose the most important feature parameters as training samples for neural network. These parameters selected should include feature information of porcelain object as more as possible and have significant representative. A lot of works has to be taken to select which samples are the useful samples for training, and a lot of training work for neural network has to be done, so the successful one of neural networks has been determined by experimentation.

Key strongpoint of this system developed is that it can diagnose porcelain quality and detect porcelain inferiors by means of collecting its waveform of vibration, i.e. AE signals, so the important develop steps is to design the function of processing original signal. That is to process the signal by useful arithmetic, and select the feature parameters of signals by experimentation. Nest step would develop and inspect the function of identifying statuses of porcelain product based on BP Neural Networks.

3. DIGITAL PROCESING UNIT

This section we'll discuss the arithmetic used in this paper and the experiment result in the digital processing unit. The signals discussed here are all discrete-time signals acquired by A/D convertor.

3.1 Sample Collection

Fig. 3 shows the some signals. There is evenness section at the left of signal each one. This section is the waiting time before object is knocked, i.e. no AE signal in this section of time. The head of signal is searched by the arithmetic as following

$$H_i = \sum_{j=p_i}^{p_i+m} |x[j]| \tag{1}$$

where x[j] is the each altitude of discrete-time

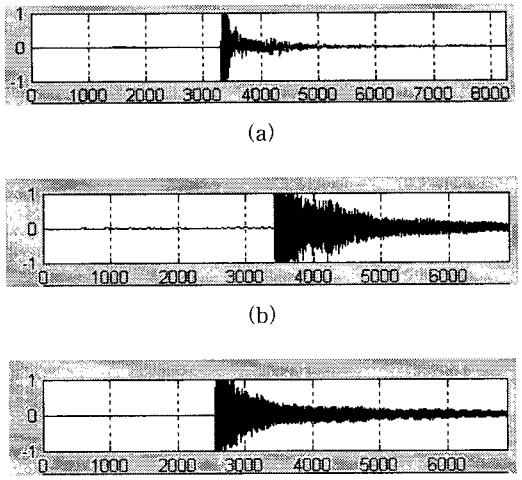


Fig. 3. The signals acquired by A/D convertor (a),(b)and(c): the signals of AE from the nick, gap and finer object respectively.

signals, positive or negative; j is the position at the discrete-time axes; p_i is the selecting position at the discrete-time axes; m is the selecting number for searching the head of signal in optimization; Hi is the calculating result.

The head of signal is confirmed according to compare Hi with Ns as following

$$H_{head} = \begin{cases} 1 & Hi > Ns \\ 0 & Hi \le Ns \end{cases} \tag{2}$$

where Ns is selected number; H_{head} is boolean variable.

When H_{head} is true or 1 at first time, it means that the head of signal is fined with pi position and is able to draw graph in Fig. 4, showing the signals started at begin of AE and the End of signal is the continuance some time in the location designed.

In order to deal with signal propriety, let to make it move parallel and make altitude of signal shrink (or magnify some times) to one unit by following.

$$y_i = \sum (x_i + 1)/2 \tag{3}$$

where yi is the result of calculation, xi is the original signal.

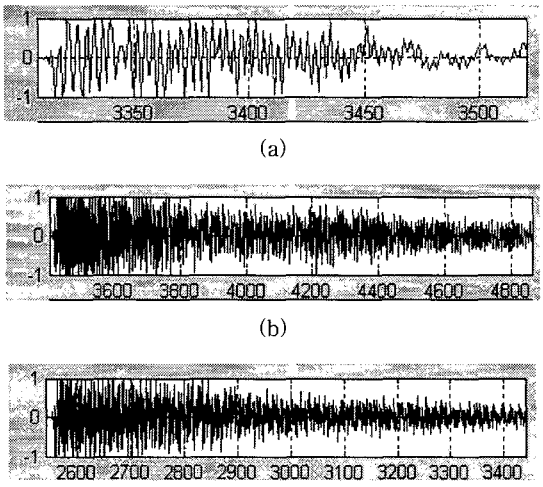


Fig. 4. The signals started at the begin of AE (a),(b)and(c) sameness with Fig. 3.

Fig. 5 shows the example for signal to be converted by formula (3). Next step is to determine the parameters.

3.2 Parameters Determination

First the statistical method in time domain is adopted and experiment is described following in this section, while the power density spectrum techniques will be adopted and discussion next step.

3.2.1 Parameters Determination in Time Domain

The processing methods here are based on probability theory and stochastic processes. What is discussed in the theoretics is a changing process governed by probabilities at each step, e.g. flipping a coin, epidemic expansion, mass traffic flow, random walk, social mobility and signal with noise. For such, and a great many other phenomena, especially the signal of AE with some noise, stochastic processes theoretics provide suitable models and methods to deal with our problem in time domain.

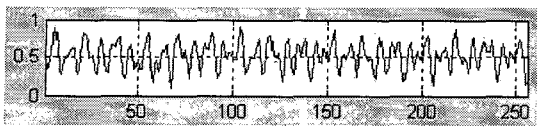


Fig. 5. The the example converted to one unit.

Problem to face is that the information about porcelain product states in the AE signal with noise has to pick-up in processing unit, so the arithmetic to solve the problem of noise disturbing is probability density function by statistical method. Taking into account as following

$$p_i = P[y_{i-1} < y < y_i] = \lim_{N \to \infty} \frac{N_i}{N} \tag{4}$$

where y is the altitude of signal in time domain; P is probability calculation; pi is the probability calculating result of altitude of signal between yi-1 and yi; N is the sampling amount of discrete-time signal; Ni is the amount of signal between yi-1 and yi;

Then N is the number limited in real-life and is not to be infinitude, so the pi is the result estimated as follows

$$\hat{p}_i = \frac{N_i}{N} \tag{5}$$

adjust it to one unit by follows

$$\hat{p}_{i(1)} = \frac{\hat{p}_i}{\hat{p}_{i(\max)}} \tag{6}$$

Fig. 6 is the distributing graph in probability calculation, with x-axis the signal altitude and y-axis the probability density.

From the graph in figure 6, we have templates as distinguishing nick with finer or gap. But the parameters in graph have 100 in number. It is too much to be as the samples. While, how many parameters to be used to train neural networks are big question, because we want to select the number of samples the less the better as long as the neural networks premise work perfectly.

Method for us to solve the question is to compare which is the most distinctiveness between real measuring signal and deterministic signals under

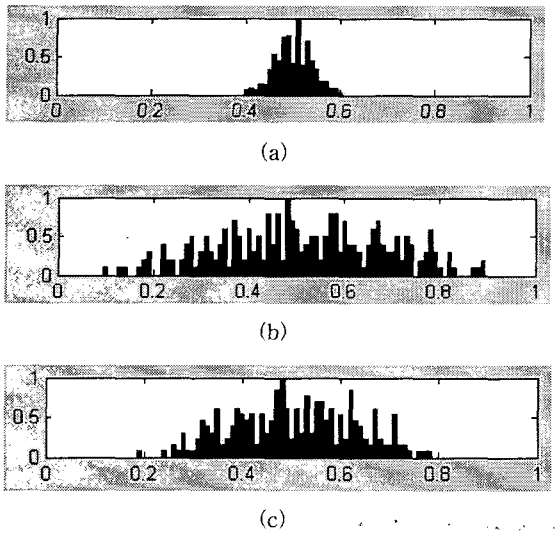


Fig. 6. Distributing graph in probability calculation (a),(b)and(c) sameness with Fig. 3.

laboratory condition. By seeking the optimization with the least-square algorithm, three position at x-axes in figure 6 are decided, 0.3, 0.65 and 0.7. So the value about y-axis corresponding with 0.3, 0.65 and 0.7 at x-axis are decided as parameters, say PM1, PM2 and PM3. PM1 = PM2 = PM3 =0, in Fig. 6(a); PM1 = 0.1, PM2 = 0.1, PM3=0.3 in Fig. 6 (b); PM1 =0.077, PM2 = 0.385, PM3=0.154 in Fig. 6 (c); In this way with more experiment we can have a group of parameter to establish first neural networks, The three inputs and Three outputs neural networks. According to the experiment and data above, the samples were collected more, and displayed some in Table 1.

Table 1. Parameters as Samples

	Input layer			Desired Output		
	PM1	PM2	PM3	A	B	C
1	0	0	0	1	0	0
2	0	0	0	1	0	0
1	0.1	0.1	0.3	0	1	0
2	0.2	0.1	0.3	0	1	0
1	0.077	0.385	0.154	0	0	1
2	0.078	0.384	0.156	0	0	1
...	...			...		

3.2.2 Parameters Determination in Frequency Domain

The power density spectrum in frequency domain is adopted and discussed in this section owing to the main power spectrum line represent AE characteristic about the object. Fig. 7 shows the graphs of power density spectrum of AE signal with the nick, gap and finer object respectively. The parameters are selected through analysing the power density spectrum graphs and selecting the particularity curve of different objector, finally making certain about the parameters in the same way like Tab.1,

Parameters selected showing peculiarity of different object are used to train another NN with 3 nodes at input layer and 3 nodes at output layer.

Another expected purpose in the experiment in frequancy domain is that power density spectrum techniques are adopted to help to select the parameters in dealing with the signals with noise.

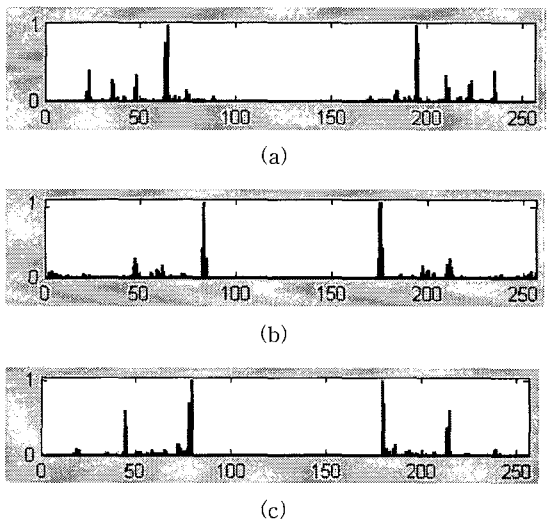


Fig. 7. The graphs of power density spectrum (a),(b)and (c) sameness with Fig. 3.

4. INTELLECTIVE SYSTEM DESIGN

Intellective system design is including neural networks design and expert decision-making de-

sign, and it is discussed in the following.

4.1 Neural Network Design

The neural network used in the system is composed of an input layer, a hidden layer and an output layer. Sigmoid function in the hidden layer is chosen as active function as follows

$$f(x)=\frac{1}{1+e^{(-x)}} \tag{7}$$

The output of neural node of output layer is

$$o_{pj}^{(2)}=f_j(\sum_i w_{ji}^{(2)}o_{pj}^{(1)}-\theta_j^{(2)}) \tag{8}$$

Neural network is designed to get a group weight value $w_{ji}^{(l)}(l=1,2)$, which made difference between its output and expected output the smallest. In that formula, p is a group samples, o_{pj} is expected output and $\theta_j^{(2)}$ is threshold value.

The neural network with 3 nodes at input layer and 3 nodes at output layer in the experiment is following:

Input layer parameters: PM1, PM2 and PM3, the results of probability calculation on signal.

Output layer parameters: A, B and C, representative nick, gap and finer individual.

The model is shown as Fig. 8. For non-linear functional approximations, NN with one hidden layer and sigmoidal-type activation functions are the most popular structures because they have proved to be capable of approximating any continuous non-linear functions.

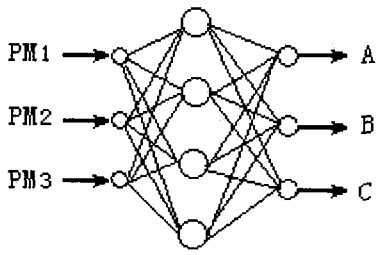


Fig. 8. The neural network model.

4.2 Neural Network Training

With enough input and output samples Table 1, neural network is trained and then a group weight value could be made certain. After training, to input a new group of feature parameters, the neural network is able to identify the status from the sample of porcelain object.

Neural network model formulation methodology includes the following steps:

1) Selection of input and output variables in digital processing and to do more experiment to get two group of data, one for training neural networks, the other for checkout to the neural networks trained.

2) Neural networks structure determination, i.e. the number of node of hidden layer, four nodes is enough here.

3) Using one group data to train neural network model, the training strategy is back-propagation so called BP neural networks.

4) Checking the effect on the neural network model trained in Step 3 with the other group.

Step 3 is the important step and is better to make clear as follows: the line between nodes in Fig. 8 names as the weight. Training the NN means to change the weight by an amount proportional to the difference between the desired output and the actual output. Weight change rule is a development of the perceptron learning rule. Weights are changed by an amount proportional to the error at that unit times the output of the unit feeding into the weight until the error is mini to desired degree.

Forward chaining of neural network is adopted as speculate mechanism. It is really the calculating process, that neural network gets an output by computing according to the input. Namely, input the feature parameters PM1, PM2, PM3 of some status to neural network, an output value OUT (relatively Status A, Status B or Status C) could be gotten by computing through every line and every node.

Running the network consists of Forward pass

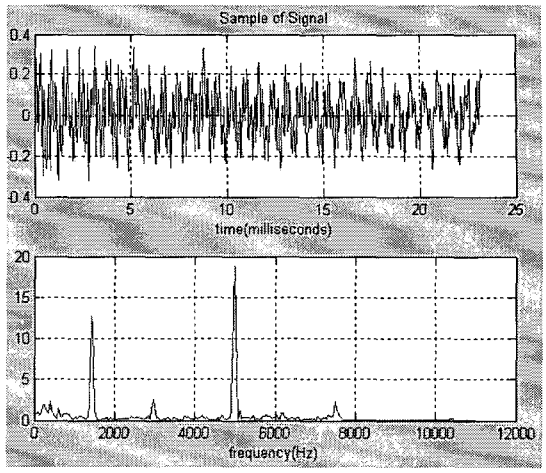
and Backwards pass. Forward pass is that the outputs are calculated in every node by formula (8), and Backwards pass is that the output unit error is used to alter weights on the output units. Then the error at the hidden nodes is calculated by back-propagation from the error at the output units through the weights, and the weights on the hidden nodes altered using these values.

Each of data pair (Input and Output Pair) to be used for NN to learn a forward pass and backwards pass is performed. This is repeated over and over again until the error is at a low enough level (or we give up). This has to do experiments good enough in this step.

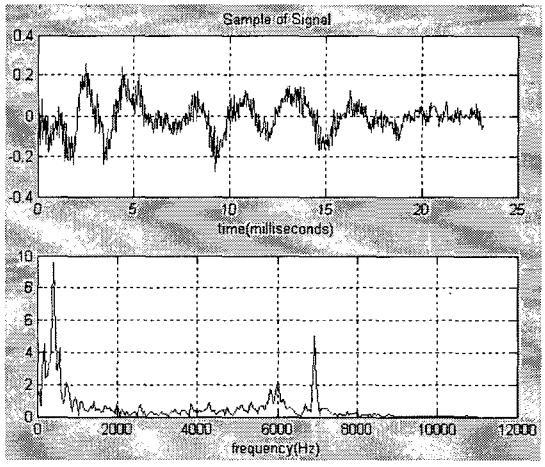
5. EXPERIMENTATION IN DETAIL

There are much different between laboratory condition and production line, so the signals collected from different place are much more different because of the more noise in production line than the laboratory condition. When the AE signal is collected in laboratory, the result of detection with parameters processed in time domain is much more right, while in noise environment, the result is uncertain. This is big headache problem. In order to solve the problem, we use a double NN, one is trained with the parameters in time domain and the other one is trained with the parameters in frequency domain. The input data to the NNs are come from diffenrent parameters, so the digital processing unit has to provide diffenrent arithmetic with time domain and frequency domain separatelly.

Experiments to some porcelain bowls are carried out respectively, The waves in time domain and in frequency domain of the bow with good and lick crack with noise are showed in Fig. 9 (a) and (b). From the graph in frequency domain, the main peak of good bowl is in high frequency point and the bowl with lick crack in low frequency point, while the frequency of noise is evenness in the whole frequency axes. So the distinguish among



(a)



(b)

Fig. 9. The signals of waves in time domain and in frequency domain of the bow with good (a) and lick crack (b).

them is taken by suitable arithmetic.

Results of detection about our first effort are much better, but the more time is needed in calculating. So there is a lot of work to do to improve the digital processing and intellective systemn latelly.

6. CONCLUSIONS

In general, it can be concluded that the design of neural networks system with digital processing

unit for detection of nick inside of porcelain with acoustic emission is successful. The BP neural network has advantage of great self-learning, high speculating speed and easy maintain, but its function could bring into play no other than the parameters are suitability. By the digital processing unit, the samples for NN are reduced to least number, and provided to training neural networks, and then put into use automatically.

Based on the power density spectrum technology, experiment in detail is necessary to deal with complex signals with noise and the parameters selected for second neural networks are useful in noise environment. So the AE signal with noise can also be used to detect the nick inside of porcelain.

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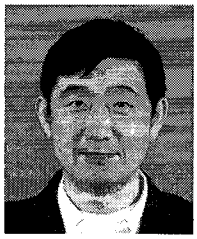

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