World Academy of Science, Engineering and Technology
International Journal of Mechanical and Mechatronics Engineering
Vol:1, No:11, 2007

A Method for Quality Inspection of Motors by Detecting Abnormal Sound

Tadatsugu Kitamoto

***Abstract*—**Recently, a quality of motors is inspected by human ears. In this paper, I propose two systems using a method of speech recognition for automation of the inspection. The first system is based on a method of linear processing which uses K-means and Nearest Neighbor method, and the second is based on a method of non-linear processing which uses neural networks. I used motor sounds in these systems, and I successfully recognize 86.67% of motor sounds in the linear processing system and 97.78% in the non-linear processing system.

***Keywords*—**Acoustical diagnosis, Neural networks, K-means, Short-time Fourier transformation

I. Introduction

MANUFACTURES including parts such as gears and springs have many components which make sound while it is moving. In recent years, a demand for silence to the manufactures has increased, so it has been important to keep quality of operating sound at constant level. In particular, manufactures that makes abnormal sound must be found accurately, in order to prevent from flowing into the following process. So far, the judgment which operating sound is normal sound or abnormal sound was hearing test by specialty workers. However, it is difficult to keep a quality at constant level, because there is a difference in each worker's measure [1] [2] [3].

In this paper, I examine a discrimination method using a technique of speech recognition, in order to automate the test as product inspection. I must consider that a distinction between normal sound and abnormal sound is very ambiguous, and that prepared samples of abnormal sound are not enough, and that there are a large number of abnormal sound types.

And so, in this paper, I propose two systems judging from case data. One is a linear processing system which uses prototypes made by K-means [4], the other is a non-linear processing system which uses neural networks trained by back-propagation [5] [6]. For a feature extraction of acoustic data, I use short-time spectrum calculated by short-time Fourier transformation. And I tested these systems using acoustic data of motors.

Manuscript received July 23, 2007.

Authors are with the School of Science and Technology, Meiji University, Kanagawa, Japan (corresponding author to provide phone: +81-44-934-7307; e-mail: ce66016@isc.meiji.ac.jp).

II. Detecting an Abnormal Sound

A. Abnormal Sound

The motor consists of the rotation axis and the cylindrically package, and so on. Normally operating motors make the sound with harmonic components at the moving operation, since pulse signals are sent to the motor. However there is a suddenly noise every spinning that are made by commingling of foreign substances, and there is a constantly noise that are made by the defective washer and by interference between the axis and the bearing.

Fig. 1 is an example of a normal sound ('ok' means good) and an abnormal sound ('ng' means no good). The abnormal sound includes extra-harmonic components.

B. Feature Extraction

When only a specific frequency band has feature of the abnormal sound, a simple band-pass filter is able to extract the feature. However when the abnormal sound occurs intermittently, a band-pass filter unfits for the feature extraction because of averaging the time varying feature. In this paper, based on the principle that the sound of normal motor is almost stationary, I use a short time spectrum which is ordinarily used in speech recognition system. I calculate amplitude spectrum in middle and under frequency band and use it as the feature, because of a number of rotations to a basic frequency can be drawn in the case of motors.

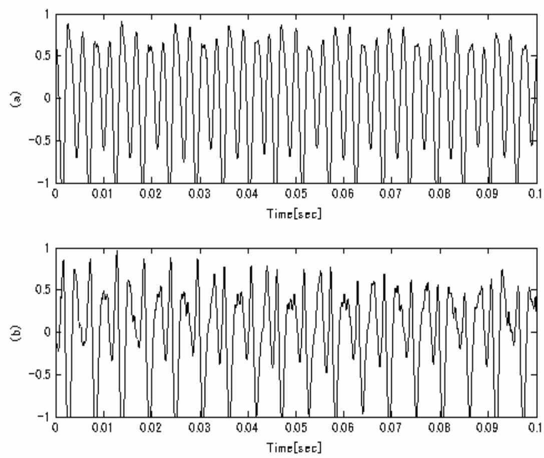


Fig. 1 Example of sounds:
(a) normal sound (b) abnormal sound

III. Theoretical Concept

In this chapter, I explain the conventional theory used in the proposed method, which are K-means used in the linear processing system, and neural networks used in the non-linear processing system.

A. K-means

K-means is a representative method of clustering that divides individuals to K classes specified in advance. A squared of Euclidean distance that is indicated (1) is used to the degree of non-similarity. And a standard of separation is the degree of non-similarity between each individual and center of clusters.

$$d(x,y) = \|x-y\|^2 = \sum_{j=1}^{p}(x^j - y^j)^2 \quad (1)$$

The algorithm of K-means is the following.

1) Specify the centers of K clusters at random as initial values.
2) Assign each object to the class of the nearest center.
3) If the assignment of all objects have not change compared with previous step, the update is over, otherwise after specifying the centers of each cluster as new centers, back in 2).

B. Neural Networks

Artificial neural networks (ANN’s) are made of arrangements of processing elements called neurons. Human brain has a variety of neurons, and some of them have advanced functions. However the most general ANN's is very simple, and it is multi-input and single-output element as shown in Fig. 2(a). Neurons are used for nodes on ANN's, and signals run one way and enter from linked neurons with the weight (w_i). After the inputting values (w_i , x_i) are summed, they are transformed by the non-linear activation functions (f), and are outputted. The output values (y) indicated statuses at that point are represented by:

$$y = f\left(\sum_{n=1}^{i} w_i x_i\right) \quad (2)$$

Various types of non-linearity are possible and some of these are hard limiter, threshold logic, sigmoidal and tanh functions.

The most popular neural networks architecture is the multi layer perceptron (MLP), the network consists of an input layer, a number of hidden layers and output layer as shown in Fig. 2(b).

MLP have been applied successfully to solve some difficult and diverse problems, and the most popular algorithm for training them as a supervised manner is the error back-propagation algorithm.

When the input and the expectation output are prepared as learning data, back-propagation algorithm learns the weight in order to bring the network output close to the expectation output. If all weights have some of value as initial value, the output of the network is $y_i^{(m)} \quad (i = 1, \cdots, N_M)$.

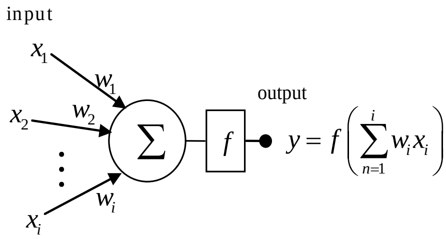
It is defined E that the summation of the square with error between the expectation output (d_i) and the network output:

$$E = \frac{1}{2}\sum_{i=1}^{N_M}\left(y_i^{(m)} - d_i\right)^2 \quad (3)$$

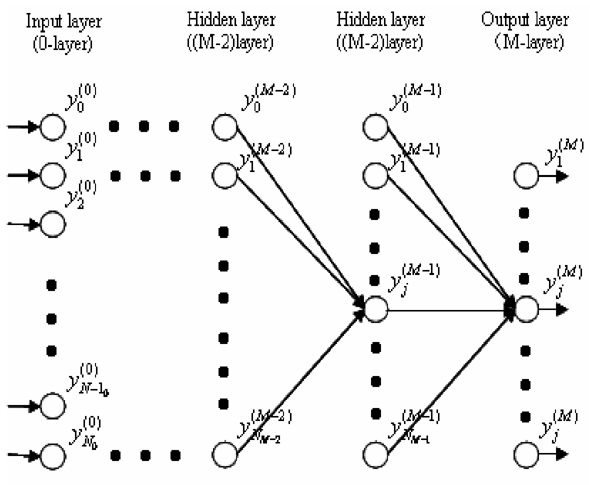
And the performance function E is made small. As a fundamental thinking, at first the partial differentiation of all weighting factors in the performance function E is computed, and if this value takes positive value, the performance function E gets bigger when the weight $w_{ij}^{(m)}$ increases, and if this value takes negative value, the performance function E gets smaller when the weight $w_{ij}^{(m)}$ increases. Therefore, the error gets smaller by degrees if the weights are updated by the following expression.

$$w_{ij}^{(m)}[n+1] = w_{ij}^{(m)}[n] - \eta\frac{\partial E}{\partial w_{ij}^{(m)}} \quad (4)$$

At this point, n is the parameter indicating the learning cycle, η is the parameter deciding the speed of convergence.



(a) Single neuron



(b) Multi-layer perceptron

Fig. 2 Neural networks

IV. Discrimination Method

In this paper, I propose two systems that differentiate normal motors from inferior goods by motor's operating sound. One is the linear processing method using K-means and Nearest Neighbor method, the other is the non-linear processing method using neural networks.

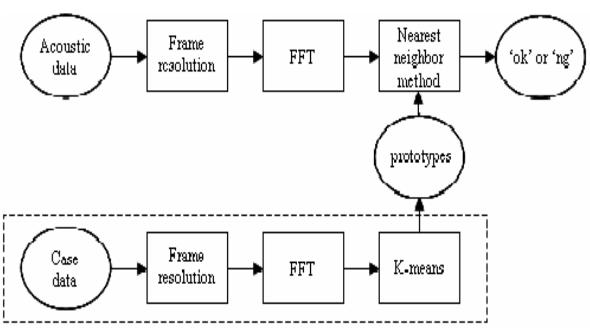
Fig. 3 is a block diagram of proposing systems. Circles in Fig. 3 express data or result; squares express process, and elements in dot-line express preparations.

A. Linear Method

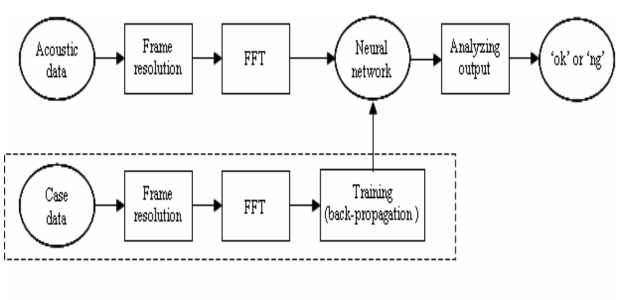
Fig. 3(a) is a block diagram of proposing linear processing system. At first, for the feature extraction, I decompose the acoustic data to frames and calculate the frequency characteristic with Fast Fourier Transform (FFT). And I use an absolute value of the result as the feature. Next, I make five prototypes with ‘ok’ data and ‘ng’ data by K-means. Prototypes are the same length as the frame length. The acoustic data is compared with prototypes by Nearest Neighbor method and judged ‘ok’ or ‘ng’. The judgment by using Nearest Neighbor method compares an input data to all prototypes with Euclidean norm.

B. Non-linear Method

Fig. 3(b) is a block diagram of non-linear processing system. Although the opening is the same as the linear processing system, I train neural networks in this system instead of making prototype. I apply a supervised learning called back-propagation as the learning method of neural networks. If input is 'ok', output of the network is vector [1,0], and if input is 'ng', the output of the network is vector [0,1]. The acoustic data pass the network, and are judged 'ok' or 'ng' by checking up output.



(a) A linear processing system



(b) A non-linear processing system

Fig. 3 Block diagrams of proposed systems

V. Simulation

A. Sample Data

In this simulation, I use sixty five motor's acoustic data that were supplied from an electronics manufacture. There are two types in the samples, fifty two 'ok' data of normally operating motors and thirteen 'ng' data of inferior goods. Beforehand all samples are divided 'ok' into 'ng' by human's determination.

The data are the length of two seconds, and are sampled by 44.1[kHz], are quantized by 16 [bit], and are the sounds of the same kinds of motors recorded by microphone. And I use the data that are down-sampled at 2000 [Hz]. In addition, Table I is the parameters of processing to samples.

B. Results

In this simulation, I used ten normal sounds and ten abnormal sounds for making prototypes and for training neural networks, and used other fifty five sounds in the evaluation experiment. In both systems, I changed the frame length to 256 [ms], 516 [ms], and 1024 [ms].

As the parameters of training neural networks in non-linear processing system, the numbers of hidden layers are from 10 to 50, the learning factors are from 0.01 to 0.05, and a numbers of training are 100000 times. And the transfer functions are the two kinds of sigmoid functions, tan-sigmoid and log-sigmoid. If the network input is n, output of the layer with tan-sigmoid function is (5).

$$\tan sig(n) = \frac{2}{1+\exp(-2\times n)} - 1 \tag{5}$$

And (6) is output of the layer with log-sigmoid function

$$\log sig(n) = \frac{1}{1+\exp(-n)} \tag{6}$$

Table II is the result of linear processing system, and Table III is the result of non-linear processing system. I obtain the result that the non-linear processing system is better than the linear processing system, and the result of non-linear processing system is as good as human's hearing test, however the recognition rate is not 100%.

The best result in non-linear processing system is 97.78%, and it means that only one sample was recognized falsely. In spite of 'ng' data, the falsely recognized sample has abnormal part only late 0.5 seconds. The sound is judged 'ok' inevitably, because the system settles the judgment using a majority decision. From this result, in this system, it is difficult to evaluate the sound data in which normal part and abnormal part are intermingled.

In both systems, the frame length for feature extraction influences the recognition. Fig. 4 shows the error convergence of each frame length when I train neural networks. As Fig. 4 shows, the longer frame length is, the smaller error is.

VI. Conclusion

In this paper, I examine a method for automation of motor's quality test. It was shown that the hearing test can be automated by the method of speech recognition; however the method is affected by the feature extraction of samples. From now, we need to conduct inspection using more acoustic data.

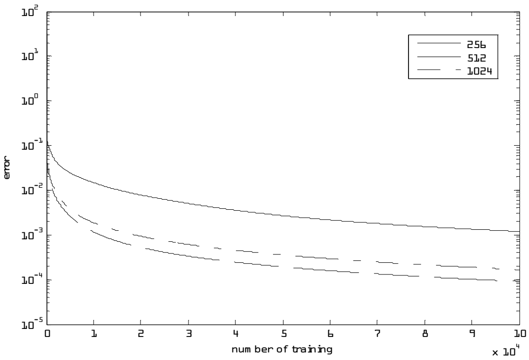


Fig. 4 The error convergence of each frame length when we train neural networks

TABLE I
PARAMETERS OF PROCESSING FOR SAMPLES

Parameter Name	Value
Sampling frequency	2000 Hz
Frame length	256, 512, 1024 ms
Window function	Hamming window
Shifting time of analysis frames	128 ms

TABLE II
RESULT OF LINEAR PROCESSING SYSTEM

Frame length	Recognition rate
256 ms	64.44 %
512 ms	82.22 %
1024 ms	86.67 %

TABLE III
RESULT OF NON-LINEAR PROCESSING SYSTEM

Transfer Function	Frame Length	Number of hidden layers / Learning factor	Recognition rate
Tan-Sigmoid	256 ms	10 / 0.01	82.22 %
	512 ms	10 / 0.05	93.33 %
	1024 ms	20 / 0.01	97.78 %
Log-Sigmoid	256 ms	20 / 0.05	86.67 %
	512 ms	20 / 0.02	95.56 %
	1024 ms	20 / 0.04	97.78 %

References

[1] H. Sugimoto and K. Fukuda, “Abnormal noise detector for gear units”, J. Acoust. Soc. Am., vol.82, pp.1856, 1987.

[2] Z.Zhang and H.Kawabata, “Study of Detection Method of Abnormal Sound Using Cellular Neural Network”, Trans. J. Soc. of Mechanical Engineers. C, vol. 69, no. 668, pp. 3207-3214, 2003.

[3] Munehiro Namba “On the quality inspection of motors by detecting abnormal noise”.

[4] S. Miyamoto, *introduction to cluster analysis* (Book style). Tokyo, CA: Morikita, 1999, pp. 13-24.

[5] G. F. Page, J. B. Gomm and D. Williams, *Application of neural networks to modeling and control* (Book style). London, CA: CHAPMAN & HALL, 1993, pp.9-23.

[6] Simon Haykin, *Neural networks* (Book style). New Jersey, CA: Prentice Hall, 1999, pp. 159-173.