Neuro-Fuzzy Classification System of The New and Used Bills

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Abstract: In this paper, we propose Neuro-Fuzzy discrimination method of the new and old bill using bill money acoustic data. The concept of the histogram is introduced to improve the processing time into the proposal system. The adaptative filter is used in order to remove the motor sound from an observed bill money acoustic data. The output signal of this adaptive digital filter is converted into not only a spectrum but also a histogram. It became easy that features of the paper money sound were extracted from the bill money acoustic data. The spectral data and the histogram is obtained like this, and it become an input pattern of the neural network(NN). Then, the discrimination result of the NN is finally judged by the fuzzy inferece in the new bill or the exhaustion bill.

1. Introduction

The money has changed with the development of the human society as the basic medium of economic worth. In the modern society, the bill money as one form of the money will have continuously and large circulated. And, a demand of full-automation operation except for business hours of Cash Dispenser(CD) and Automated Teller Machine(ATM) heightens. For the reason, it is important that it would not cause the blockage of the bill money. However, it is necessary that becoming a bill is exchanged for the new bill money by examining the condition of bill, since damage bills by fouling and fracture arises in great numbers. Therefore, it has been separated to again available bills and bills with the difficult utilization in Bank of Japan. On the new and old discrimination of the paper money, the various research is carried out by the present. Before, we proposed the discrimination technique which introduced an adaptation signal processing and an intelligent information processing[1]. In the case of the discrimination using the bill money acoustic data, not only the bill money sound but also the sound(motor sound) as a motor and a roller rotate are included for an observation data. Therefore, it is important to extract the high-precise bill money sound. Then, we extracted the high-precise bill money sound using 2-stages adaptive filter[1]. And, the good discrimination result was obtained in the experiment using the NN[2]. Especially, it was possible to carry out the new and old discrimination of the bill money by the experience in the specialist in proportion to the degree of exhaustion in the introduction of the fuzzy inferece[3]. However, high-speed processing is necessary in order to use practically. Then, the processing time was reduced by creating the histogram from an observation, in this paper. It became possible that the cost reduction of the hardware and the compactness of the equipment were considered in order to use the new and old discrimination machine practically. This study quantitatively verifies proposal of the new and old discrimination algorithm which satisfied a demand like the above and the effectiveness by the simulation.

2. Acoustic Data of Bill

In this paper, input signal as an object of the processing are acoustic data of bill got from the bill discrimination machine. The observation signal is collected from the microphone installed in the bill discrimination machine. The measurement system is shown in Figure 1. There is a part involved in the roller of the flocking equipment, when the bill carried in the bill discrimination machine. Then, the bill sound is generated, when the bill passes there. The sound is collected by the microphone, and the signal which became discrete by the AD converter is recorded after it is amplified by the amplifier. The sampling frequency is 50[kHz], and the recording time is 0.2sec. Therefore, the sampling interval is 20μsec, and 10,000 data is recorded on one signal. By doing like this, got observation data are shown in Figure 2. Figure 2(a), (b) is respectively a time-series signal of observation data of new card and exhaustion card. And, the header signal shown in Figure 2 is measured in the system of Figure 1 in order to show

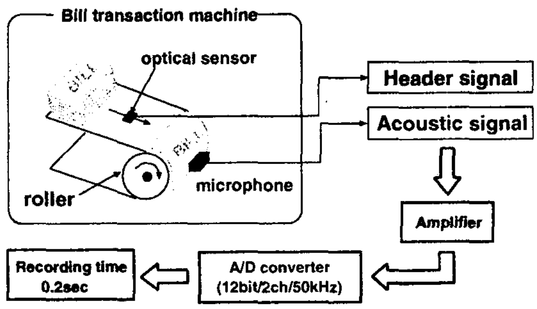
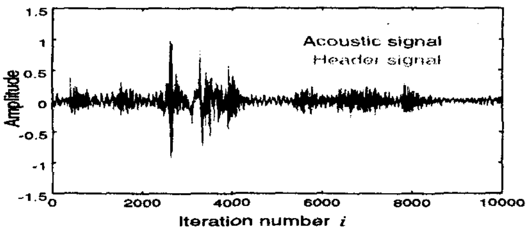
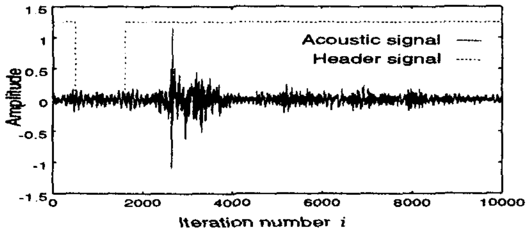


Figure 1. Acoustic data measurement system of the bill discrimination machine.



(a) New bill



(b) Used bill

Figure 2. Acoustic data of bills.

a charge time of the bill. Therefore, it is possible to extract the region of the bill sound. Concretely, the bill passes this sensor, and it reaches the entrance of the bill discrimination machine in about 0.02[sec] (1,000 data), and the bill sound is generated in about 0.031[sec](1,536 data). In observation data of Figure 2(a) and (b), motor sound and noise have appeared in the whole region ($0 \leq i < 10,000$). Here, the suffix i shows the iteration number.

3. Classification System

The classification system is illustrated schematically in Figure 3. In this case, the noise is entrapped with not only the bill money sound but also a sound(motor sound) as motor and a roller rotate in an observed acoustic data. An adaptive filter is used in order to extract the paper from the observation bill money sound. The spectral data and the amplitude histogram are respectively formed from the FFT and amplitude distribution analysis. And the new and old discrimination of the bill money is carried out using the NN and fuzzy inference[2][3].

3.1 Detection of Bill Sound

An adative filter is used in order to extract the bill sound which removes the motor sound from the observation data shown in Figure 2. The basic noise-canceling filter is illustrated in Figure 4. The adpative filter consists of two distinct parts: a digital filter with adjustable coefficients, and an adaptive algorithm which is used to adjust or modify the coefficients of the filter. An adaptive algorithm with the NLMS[5] using coefficient, w_i, is given by

$$\begin{aligned} w_{i+1} &= w_i + \frac{2\mu}{N\hat{\sigma}_i^2} e_i x_i \ (0 < \mu < 1) \quad (1) \\ \hat{\sigma}_i^2 &= \beta x_i^2 + (1-\beta)\hat{\sigma}_{i-1}^2 \ (0 \leq \beta \ll 1) \end{aligned}$$

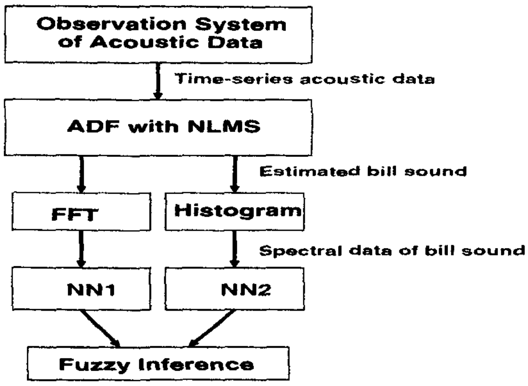


Figure 3. Discrimination system of the new and used bills.

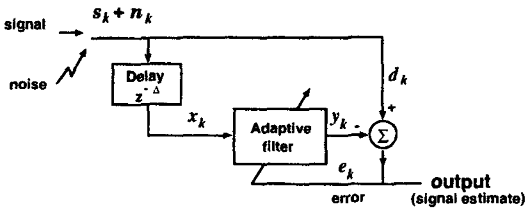


Figure 4. Noise canceling filter.

where μ is the convergence parameter, e_i is the error signal, x_i is the input signal, N is the order of adaptive filter, and i is the iteration number. Note that $\hat{\sigma}$ is a time-varying estimate and β is a forgetting factor.

3.2 Amplitude Distribution Analysis

The amplitude distribution analysis does sampling of the time base and quantization of the amplitude for some signals, as it is shown in Figure 5. The value in proportion to the amplitude value is designated, and the operation which does +1 of the content is executed in the selected time period. Thus, the histogram of the amplitude distribution in this time is obtained. And, These results are used as an input pattern of the NN.

3.3 Spectral of Bill Sound

The processing which converts into a spectral data from the estimate bill sound in shown in Figure 6. Time-series data is converted into spectral data using the FFT with 512 points. This is also used like the histogram as

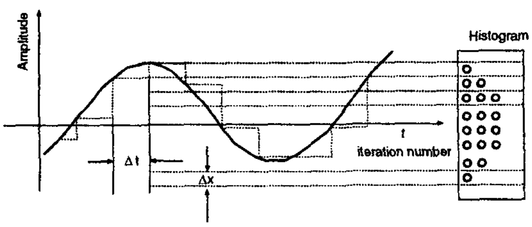


Figure 5. Amplitude Histogram

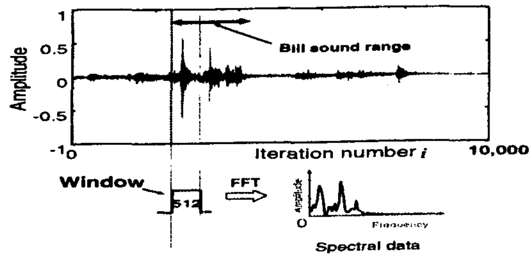


Figure 6. Spectral data of an estimated bill money sound.

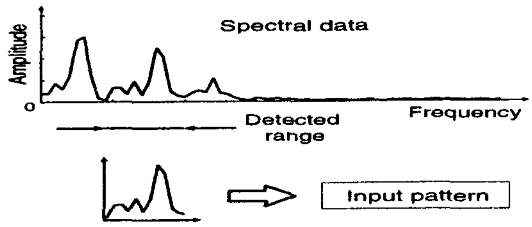


Figure 7. An input pattern for the NN.

an input pattern of the NN. It is possible to reduce the number of the neurone of input layer of the NN, and it can be expected that the speedup of the discrimination is attempted. The selection method of the input pattern of the NN is shown in Figure 7. From one estimation bill sound, one spectral data is obtained. The NN is multilayer structure, and the learning is performed using the BP method. Then, the discrimination result of the NN is finally judged by the fuzzy inference in the new bill money or the exhaustion bill money. It is possible to deal with the new and used ambiguity in the bill money by using the fuzzy inference. Here, We will omit the explain regarding the NN.

3.4 Fuzzy Inference

The fundamental inference method used in fuzzy control is explained. In the next fuzzy rule 1 and rule 2, let we set x_1^o and x_2^o was respectively observed for input x, y.

rule 1 : *if* (x_1 *is PM*) & (x_2 *is ZO*) *then* y *is ZO*
rule 2 : *if* (x_1 *is ZO*) & (x_2 *is PM*) *then* y *is NM*

In general, we let the compatibility for antecedent "x is A" be $A(x^o)$, that is, the membership function of x^o for fuzzy set A. Now let the input be $x_1 = x_1^o, x_2 = x_2^o$. In case of rule 1 and rule 2, the membership function g_{01}, g_{02} will be obtained as following.

$$g_{01}(y) = (\mu_{PM}(x_1^o)\Delta\mu_{ZO}(x_2^o)) \bigcirc \mu_{ZO}(y) \quad (2)$$
$$g_{02}(y) = (\mu_{ZO}(x_1^o)\Delta\mu_{PM}(x_2^o)) \bigcirc \mu_{NM}(y) \quad (3)$$

Here, Δ shows fuzzy logic operation AND(MIN). And, $\bigcirc$ is called T-norm operator of the generalization synthesis rule. Let the norm operator be $\cdot$ (multiplication), then, the membership function becomes respectively

$$g_{01}(y) = \omega_{01} \cdot \mu_{ZO}(y) \quad (4)$$
$$g_{02}(y) = \omega_{02} \cdot \mu_{NM}(y) \quad (5)$$

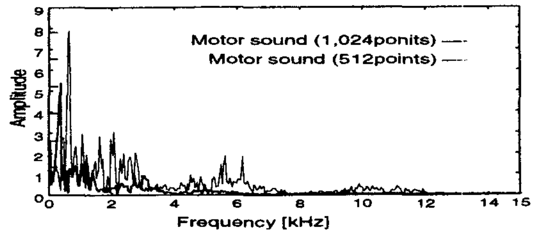
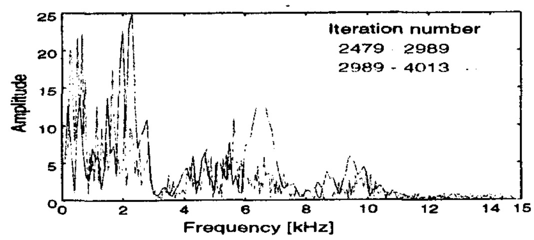
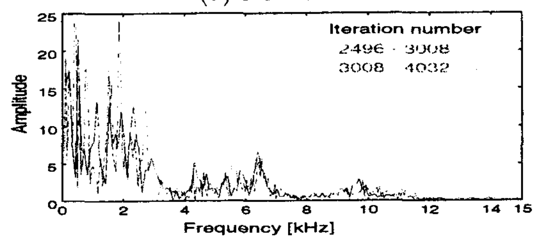


Figure 8. Spectral of motor sound.



(a) New bill



(b) Used bill

Figure 9. Spectral data of an observation data.

where

$$\omega_{01} = \mu_{PM}(x_1^o)\Delta\mu_{ZO}(x_2^o)$$
$$\omega_{02} = \mu_{ZO}(x_1^o)\Delta\mu_{PM}(x_2^o)$$

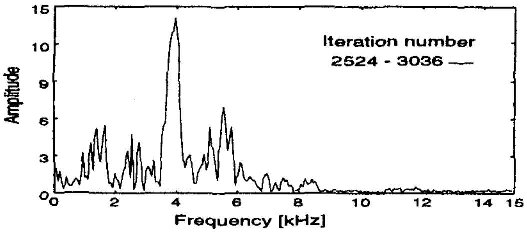
As a final conclusion, it will be

$$g_0(y) = \nabla_{i=1,2}\, g_{0i}(y) \quad (6)$$

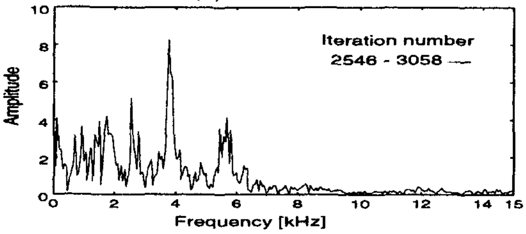
where ∇ is the fuzzy logic operation OR(MAX).

4. Experiments and Results

The computer simulation is performed using acoustic data obtained from actual bill money discrimination machine. And the discrimination system for this experiment is shown in Figure 3. First of all, in order to see the influence of motor sound, we take out the data from the motor sound range of the observation data. This data is transformed into spectral data using the FFT with 512 points. The result is illustrated in Figure 8. From this figure, we can find that the motor sound almost distributes in the frequency range which is about from 0[kHz] to 12[kHz]. And, we detect the data from the bill sound range of an observation data for the new and used bill, respectively. These results are illustrated in Figure 9. From Figure 8 and 9, we can find the frequency band of the bill sound and the motor sound intermingles within being wide. Now, the adaptive filter

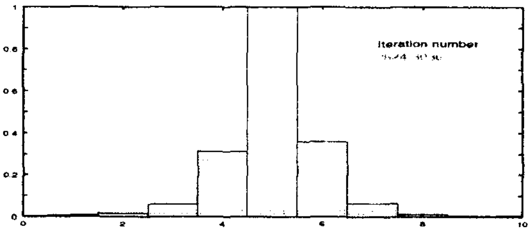


(a) New bill

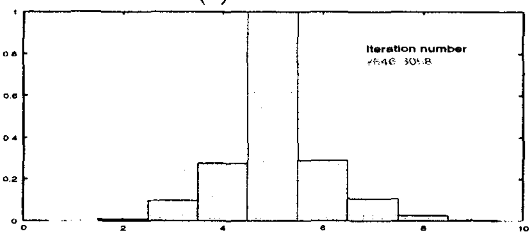


(b) Used bill

Figure 10. Spectral data of an estimate bill sound.



(a) New bill



(b) Used bill

Figure 11. Amplitude histogram of an estimate bill sound.

is set in order to extract the bill sound. We consider an adaptive filter with the NLMS algorithm as $N = 5$, $\mu = 0.01$, $\beta = 0.01$. As an example, the spectral data of filtering results in the bill money sound are illustrated in Figure 10. The elements of the filtering results into 10 equally speced containers, and the histogram is decribed by the number of elements in each container. An amplitude histogram of filtering results is illustrated in Figure 11. The NN1 is set as 10-40-2 network construction. From Figure 9 and Figure 11, we can find that the motor sound and noise are sufficiently eliminated by the adaptive filter. The frequency distribution of the bill sound is shown in Figure 11. Hence, we can limit some spectral data area as the input to the NN2, and the frequency band from 0[Hz] to 15[kHz] is used. In this experiment, we collected 18 acoustic data of the bills for each category. One sectional pattern for each

Table 1. Classification results

	NN1	NN2	Fuzzy
New bills	12/15	13/15	14/15
Used bills	14/15	13/15	15/15

time-series acoustic data are achieved by using window function. 0.03 and 0.001 were respectively set as the training factor and the goal error in the NN1 and the NN2 with the BP algorithm. Here, 3 data was randomly chosen from 18 data, and it was made to be the learning data for each categories in the NN1 and the NN2. After training of the NN1 and NN2, the remaining 15 data for each category are respectively used to obtain the classification performance of the new and used bills. An output of the NN1 and the NN2 are made to be the fidelity required according to the fuzzy inferece. For two input patterns which consist of one bill data, the final judgment is performed using the MAX operation. The classification results are illustrated in Table 1 where the denominators are total number of checking patterns and the numerators are the number of correct classification.

5. Conclusions

In this paper, the discrimination considering the ambiguity as an exhaustion became possible by using fuzzy inference and the NN. The new and old discrimination accuracy of the paper money which exceeded 90% by this proposal technique was obtained. It was verified that this proposal technique was effective by the simulation for the new and used discrimination of bill money. By the introducing the amplitude histogram, it became possible that the processing time was reduced. In the future, it is to design so that the real-processing may became possible.

Acknowledgments

In this paper, acoustic data of bills were offered from Glory, Ltd.. I am thankful for the cooperation of the party of Glory, Ltd..

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