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Expert System for Signature Analysis

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ABSTRACT

Vibrating Machinery Noise, – airborne, structureborne or waterborne – has a signature characteristic of the combination of machinery, its mounting, load coupling, and the structure. FFT and RTA are standard techniques for obtaining power spectral density (PSD) of the noise from the source. In this paper a technique of extraction of features from the PSD, and classification of the sources is presented. An expert system is reported which classifies if the same source has appeared second time. It also gives the degree of confidence to which the classification is made to the operator.

1. INTRODUCTION

Vibrating machinery noise – airborne, structureborne or waterborne – has a signature, characteristic of the machinery, couplings, mountings etc. It is desirable to identify the source or classify th se according to the features exhibited in the signature. In the following paragraphs, an expert system which can classify the sources according to distance criteria is reported.

The pattern of the peaks in the spectrum is called signature. The peaks have a definite relationship with each other and they shift together as the shaft speed (rpm) increases or decreases. Certain unconnected resonance peaks appear and disappear in each spectrum for different shaft speeds. These resonance peaks confuse the identification process when identification is required independent of shaft speed (rpm). The patterns of signatures are identifiable with a certain degree of of confidence by computing the feature distance measures. Against one set of rules, an expert system is designed to classify/identify the sources of the signatures.

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2. SIGNATURE ANALYSIS

The power spectral density (PSD) of the radiated noise of a source is picked up by a hydrophone. The hydrophone output is connected to a Nicolet Spectrum Analyser. The power spectrum is computed in 1/3 octave bands. Corrections for changes in distance and frequency dependent attenuation are applied to the spectrum. A number of snap shots of PSD's are taken and the averaged PSD is taken as representing the source.

The data is normalised according to the relation.

$$Xi = \left[\frac{x_i - \mu}{\sigma} \right]$$

Where Xi is the normalised value at a frequency of source i. Xi is the raw data, μ and σ^2 are the mean and variance of the raw data.

Fig. 1 shows (a) typical power spectrum of a radiated noise source, (b) its normalised spectrum, and (c) power spectral density PSD of different sources.

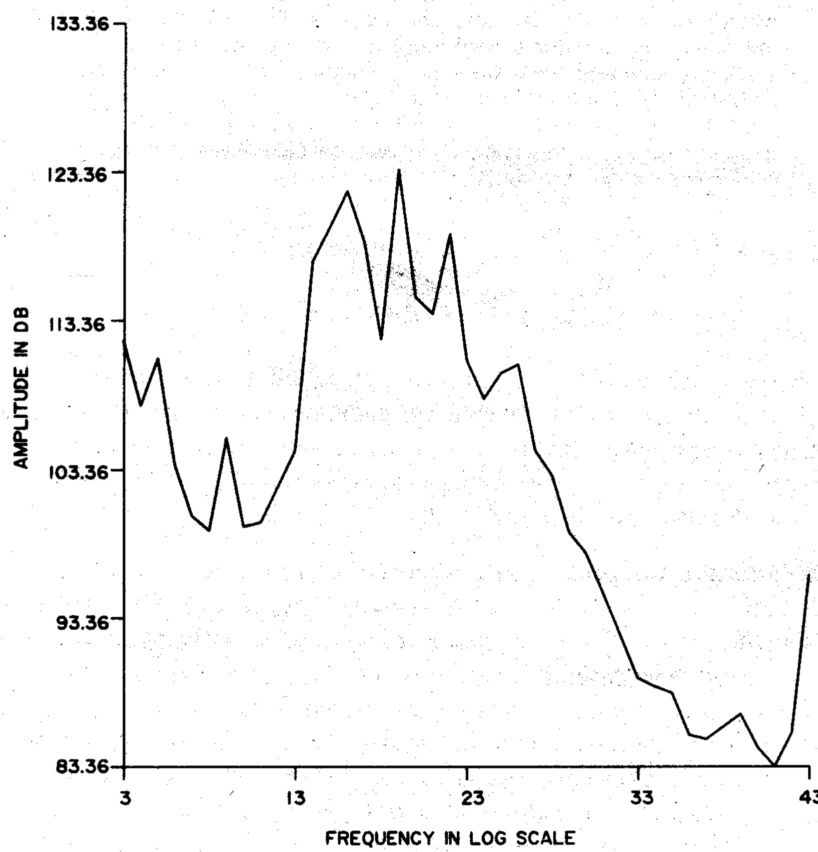

Figure 1(a). PSD of machine 2.

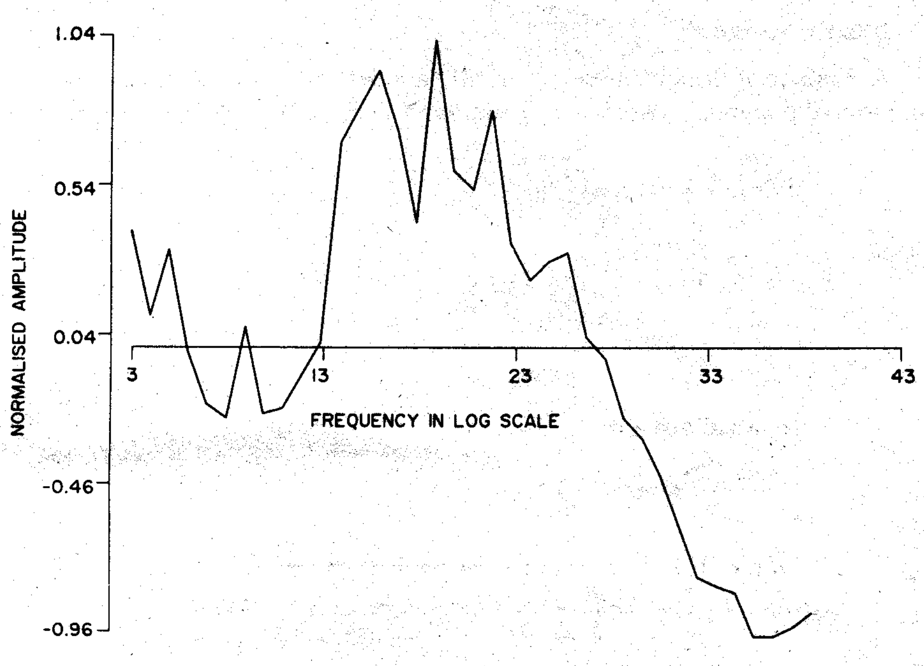

Figure 1(b). Normalised spectrum of machine 2.

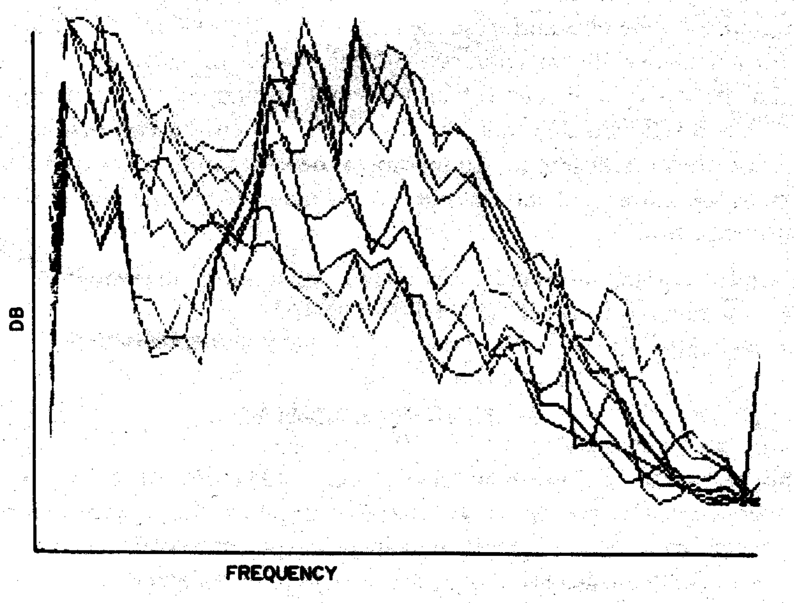

Figure 1(c). PSD of different sources.

2.1 Distance Measure

A number of distance measures (DM) are defined in literature[1] to measure the closeness of features between two signatures*X* and *Y*. The following are used.

1. Euclidean distance

$$d(X, Y) = \left[\sum_{i=1}^{n} (x_i - y_i)^2 \right]^{1/2} \tag{2}$$

2. Correlation distance

$$d(X, Y) = \frac{\sum_{i=1}^{n} (x_i - \mu_x)(y_i - \mu_y)}{\left[\sum_{i=1}^{n} (x_i - \mu_x)^2 \sum_{i=1}^{n} (y_i - \mu_y)^2 \right]^{1/2}} \tag{3}$$

The Euclidean distance between two signatures *X* & *Y*, when 0, indicates identity of two signatures, and when >>0, the dissimilarity. On the otherhand, the correlation disatance, if equal to 1, indicates identify of the two signatures and if <<1, the dissimilarity.

The speed of the DM as the rpm of the source changes, is an important factor (this introduces doppler shift and resonance peaks). Therefore, the spread of the DM is identified in terms of μ and σ. A measure 'Threshold value' *T* is defined as $T = \mu + \sigma/2$ for correlation distance and $\mu - \sigma/2$ for Euclidean distance. A decision rule is made that if DM of one source feature vector to another source feature vector is greater (less for Euclidean) than the threshold *T* then the two belong to the same class, if not, they are different. An unknown, new signature is compared with the set of previous signatures and the classification is made. A change in threshold changes the confidence level.

A typical example of rules, decision and explanation are given in Appendix. The complete signature analyser EXPERT SYSTEM is implemented on IBM PC compatible computer.

3. SIGNATURE ANALYSER

This has got the following building blocks: (i) Pre-processor, (ii) Expert system, (iii) Decision display, and (iv) User interface. Input to the signature analyser is the frequency spectrum of the current machine. Out put of the signature analyser is the display of the classification decision, degree of confidence and new or old machine. A block diagram of the complete signature analyser system is shown in Fig. 2. The detailed descriptions of individual blocks are given below.

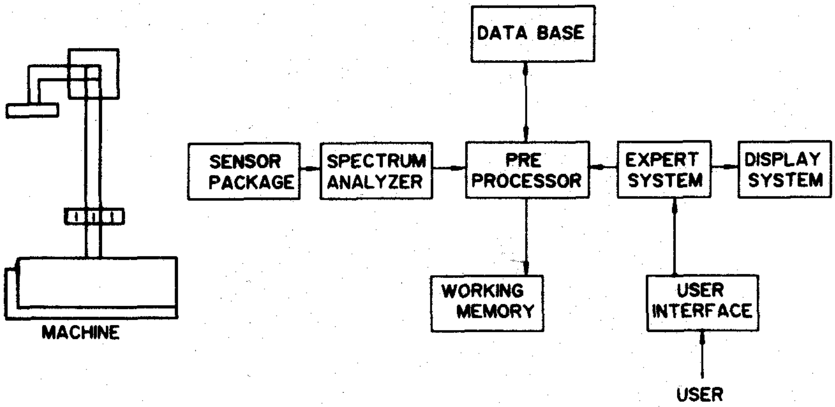

Figure 2. Signature analyzer-block diagram.

3.1 Pre-processor

The main function of the pre-processor is (i) frame averaging of spectrum, (ii) normalisation of spectrum, and (iii) distance measure computation.

N-lines of discrete spectrum of vibration noise after the preprocessing are taken as machine feature vector. These N-frequency lines fix a machine in N-dimensional Euclidean space. In classification, the distance of the current machine position in Euclidean space with respect to M-clusters is found. Based on certain rules designed, the machine is classified to be a member of one of the M-clusters or can form a separate member forming $(M+1)$th cluster. Pre-processor computes the distance measure with all the K number of points in the Euclidean space. This provides K-measures. Pre-processor operates on 2 types of memory : (a) Data-base for the different machine-feature-vectors, which is updated with current machine feature by the pre-processor upon the user update command, and (b) working memory where the computed distance measures and statistics of the current machine feature vector are stored[2].

3.2 Expert System

The block diagram of the Expert System is shown in Fig. 3. The signature verification and classification from the distance measure matrix involves human experience. This human expertise of classification and verification are framed as a set of rules with conditional values and proper action statements/facts. The expert system works on these rules.[3] The set of facts for the expert system to operate are provided by the K distance measures of the current machine vector in the working memory. Expert System also operates on the facts available in the static memory. These are called static facts and are updated by the facts in working memory by user Command. The knowledge here consists of 'If-condition-then-action-rules'. The inference engine has interface mechanism and control mechanism. Inference engine interacts with user and display. Inference engine operates on the facts in the working memory and static

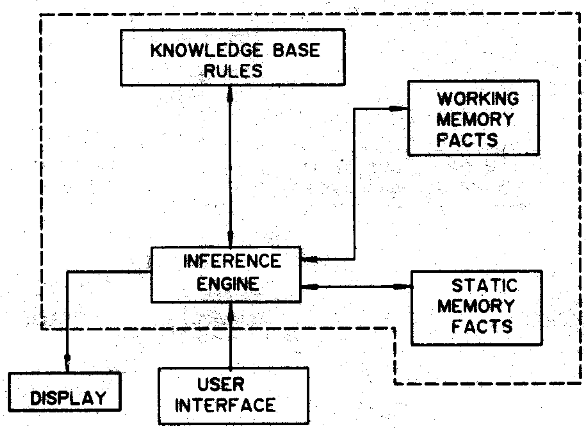

Figure 3. Expert system-block diagram.

memory and fires the rules in the knowledge base. Once the goal is reached, decision is displayed on the screen.

3.3 Decision Display

The details displayed as a consequence of the decision by the Expert System are :

(a) Classification statement if the current machine is a new machine.

(b) Signature verification statement if the current machine is not a new machine.

(c) If it is classified, what are the other members of the cluster.

(d) After the display of the Expert decision, system waits for user interaction.

3.4 User Interface

After the display of the decision, the system queries the user whether user requires any explanation. If required, it provides the explanation by giving the different distance measures of the members of the clusters and threshold obtained through computation. Then the sytem queries for final classification against the library of signatures and their classification. Through this interface, user can (i) update the data base with the current machine feature vector in the pre-processor, and (ii) update facts in static memory with the facts in working memory.

4. CONCLUSION

A PC based Expert Signature Analyser System is presented. This system is tested with the discrete spectrum of 9 machines and the Expert System decisions are very encouraging.

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2. Waterman, D.A. & Hayes-Roth, Frederick, Pattern-Directed Inference System, (Academic Press, New York), 1978, 155–176.
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APPENDIX

1. A typical classification display is shown here.
   - (a) New machine __________ belongs to the class _______.
   - (b) The other members of the class are ______________.
   - (c) Do you want explanation (Yes/No) _______.
   - (d) Do you want to update (the data base and static memory) (Yes/No) _______.

2. A typical explanation process for the classification decision is shown here.
   - (a) The threshold obtained for this computation is _______.
   - (b) The distance between Machine 1 and New Machine is _____.

     The distance between Machine 2 and New Machine is _____.

     The distance between Machine 3 and New Machine is _____.
     and so on.

3. A few typical rules provided in the knowledge base are given here.

RULE 1

IF X IS 1

AND Y IS 1

AND Z IS 1

THEN P IS 1

RULE 2

IF A IS ___ EQUAL ___ TO B

THEN Z IS 1

RULE 3

IF E IS LESS THAN 0.05

THEN IDENT IS 1

RULE 4

IF IDENT IS 1

THEN DISPLAY IDEC

In these rules

- X,Y, are variable facts provided by the working memory and static memory.

* P,E,Z are dynamic facts.

* Once inference mechanism encounters DISPLAY, goal is reached and process IDEC is displayed (IDEC = identification DECISION).

4. A typical distance matrix for 9 machines using correlation matrix is given below.

Machine No.	3	6	2	7	8	9	4	1	5
3	0	0.36	0.19	0.44	0.38	0.40	0.09	0.26	0.44
6	0.36	0	0.33	0.22	0.24	0.17	0.36	0.21	0.23
2	0.19	0.33	0	0.40	0.37	0.35	0.18	0.22	0.38
7	0.44	0.22	0.40	0	0.18	0.19	0.44	0.27	0.13
8	0.38	0.24	0.37	0.18	0	0.24	0.40	0.28	0.20
9	0.40	0.17	0.35	0.19	0.24	0	0.402	0.23	0.16
4	0.09	0.36	0.18	0.44	0.40	0.402	0	0.25	0.44
1	0.26	0.21	0.22	0.27	0.28	0.23	0.25	0	0.26
5	0.44	0.23	0.38	0.13	0.20	0.16	0.44	0.26	0

RESULTS

From the distance matrix computed the following values are obtained.

$$\text{Threshold} = \frac{\sum \text{distance measures}}{N} = 0.2863$$

The threshold array is filled according to the rule :
If distance (i) < threshold, THAR (i) = 1
else THAR (i) = 0

Class array	Threshold array
1	0
2	1
1	0
2	1
2	1
2	1
1	0
1	1

Execution of the rules in the rule base uses the above class array and the threshold array.

The resulting decision display is shown in Fig. 4. The classification decision is independent of the sequence of machines read.

Classification decision

According to the classification decision rules given in the text, machines 1,2,3 and 4 are clustered in one class and machines 5,6,7,8 and 9 are clustered in another class. This classification conforms to *apriori* knowledge of the machines.

THE MACHINE READ IS : S52

MACHINE 9 BELONGS TO CLASS 2

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* * * * * * * * * * * * * * * * * *

THIS MACHINE HAS NOT BEEN IDENTIIFIED

* * * * * * * * * * * * * * * * * *

THE OTHER MEMBERS OF THE CLASS ARE :
M/C : 2   M/C : 4   M/C : 5   M/C : 6

DO YOU WANT EXPLANATION?
? Y

THE THRESHOLD OBTAINED FOR THIS COMPUTATION IS .2863493

DISTANCE BETWEEN NEW M/C & M/C 2 IS : .4405383

DISTANCE BETWEEN NEW M/C & M/C 2 IS : .22724448

DISTANCE BETWEEN NEW M/C & M/C 1 IS : .3818008

DISTANCE BETWEEN NEW M/C & M/C 1 IS : .1283255

DISTANCE BETWEEN NEW M/C & M/C 1 IS : .2037217

DISTANCE BETWEEN NEW M/C & M/C 1 IS : .1619099

DISTANCE BETWEEN NEW M/C & M/C 1 IS : .442022

DISTANCE BETWEEN NEW M/C & M/C 1 IS : .2574274

DO YOU WANT FINAL CLASSIFICATION?
? Y

THE FINAL CLASSIFICAITON OF THE MACHINES
IN THE LIBRARY ARE :

MACHINE	1	BELONGS TO CLASS :	1
MACHINE	2	BELONGS TO CLASS :	2
MACHINE	3	BELONGS TO CLASS :	1
MACHINE	4	BELONGS TO CLASS :	2
MACHINE	5	BELONGS TO CLASS :	2
MACHINE	6	BELONGS TO CLASS :	2
MACHINE	7	BELONGS TO CLASS :	1
MACHINE	8	BELONGS TO CLASS :	1
MACHINE	9	BELONGS TO CLASS :	2

DO YOU WANT TO UPDATE?

Fig. 4 Decision display