RADC SEISMIC CLASSIFIER DESIGN

Albert H. Proctor, et al

Rome Air Development Center
Griffiss Air Force Base, New York

August 1973
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Albert H. Proctor
James E. Roach
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Approved for public release; distribution unlimited.

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FOREWORD

This in-house technical report describes work conducted under the Advanced Development Program, Project 692B, Advanced Sensor Technology. The report has been reviewed by Mr. Robert Curtis, Project Engineer, and has been designated as unclassified material.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS).

This technical report has been reviewed and is approved.

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**This report describes the design and evaluation of seismic classifiers for distinguishing humans, heavy trucks, armored personnel carriers, helicopters, and C-131 aircraft. The data used to develop these classifiers consisted of many digitized seismometer responses to each of the intrusion targets and was collected by RADC (DCTI) at the West Lee Test Site. RADC (ISCP) analyzed this waveform data and extracted an initial set of 48 features. The On-Line Pattern Analysis and Recognition System (OLPARS) was then used to**
20. ABSTRACT (continued)

develop several seismic classifier designs which are based on different sub-
sets of the initial 48 features.
This report describes the design and evaluation of seismic classifiers for distinguishing among humans, heavy trucks, armored personnel carriers, helicopters, and C-131 aircraft. The data used to develop these classifiers consisted of many digitized seismometer responses to each of the intrusion targets and was collected by the Sensor Development Section of the Surveillance and Control Division (DCTI) at the West Lee Test Site. The Interactive Processing Section of the Information Sciences Division (ISCP) analyzed this waveform data and extracted an initial set of 48 features. The On-Line Pattern Analysis and Recognition System (OLPARS) was then used to develop several seismic classifier designs which are based on different subsets of the initial 48 features.
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SECTION I

INTRODUCTION

This report documents the first attempt to design linear classification logic based on seismic waveform data collected at RADC's West Lee Test Site. This decision logic was designed to distinguish among humans, heavy trucks, armored personnel carriers, helicopters, and C-131 aircraft. The classifier design procedure employed the following sequence of tasks:

- Data Collection
- Development of an Interactive Graphics Tool for Data Analysis
- Data Analysis
- Development of an Automatic Segmentation Algorithm
- Feature Hypothesis
- Feature Extraction
- Feature Evaluation
- Classification Logic Design
- Testing Classification Logic with Independent Test Data

This effort was conducted in support of Project 692B of the Advanced Sensor Development Program. The seismic classifier designs discussed in this report are based entirely on data collected by the Sensor Development Section at its West Lee Test Site and made available to the Interactive Processing Section for completion of the remaining tasks of the classifier design procedure.
SECTION II
DATA COLLECTION AND CONVERSION

The seismic database used to design the October 1st Intrusion Classifier was collected and digitized by DCTI at the West Lee Test Site in the first quarter of 1972. The five classes of intrusions observed were helicopters, armored personnel carriers, C-131 aircraft, heavy trucks, and humans. Background data was also collected and used to determine a suitable detection threshold for the turn-on criteria.

The test procedure, following calibration, consisted of running the intruders along one of five specific paths at several known constant speeds. Each intrusion was repeated with each speed, path, and direction as a check on repeatability. Each intrusion involved only one object, with the exception of humans where there were multiple as well as single intrusions. Each sensor was a three-axis low frequency geophone, Geo-Space Model VLF-LP-3D, with one vertical and two horizontal axes (parallel and perpendicular to the intrusion paths).

As the intrusions were taking place, the seismic transducer signals were relayed by underground cables to the site control center, digitized, and recorded directly on digital tapes in the BAMKI format. This format is capable of packing 45 simultaneous sensor waveforms on the tape. Since the...
experiment involved 3 three-axis geophones, the BAMKI format sparsely packed 9 of the 5 possible channels of digitized waveforms on each tape. Each file on the tape contained one intrusion run, consisting of a number of 320 sample records. First, the data was filtered at 500 Hz and then digitized at 1000 samples per second. Each sample value was quantized to any of 1023 values ranging from -2044 to +2044 in steps of 4. The corresponding strip chart range was ±10 volts maximum. Each test usually produced three or four magnetic tapes. Although the BAMKI format was able to record all the sensor data in real time, it caused many tape read problems which delayed processing the tape at the Honeywell 635.

While the BAMKI format offered some advantages, it also has many deficiencies. The time required to unpack the 45 simultaneous data channels made the BAMKI format unwieldy for quick access and analysis of the data. These tapes contained aborted runs which should have been deleted but were mixed in with the valid runs. Also a software bug in the PDP-9 magnetic tape driver resulted in a high rate of parity errors when we tried to read these tapes at the Honeywell 635. For these reasons, the seismic data was stripped from the BAMKI tapes, edited, and formatted more simply on other tapes. These new tapes presented the advantages of clean, parity error free data and a simple format which made the data easily accessible.
SECTION III
SEGMENTATION

In order to analyze "clean" data, i.e., data which is truly characteristic of each target class, a criterion was developed to cut data from each run and save only a meaningful portion of the run. This segmentation operation is useful because (1) it presents only the statistically significant data to the decision making stage of logic, thus promising higher recognition rates, and (2) it reduces the amount of time the sensor must be processing data for decisions, thus reducing power requirements and extending sensor life.

Development of a segmentation procedure requires one major step in common with feature design: extensive visual study of the waveforms on hardcopy or graphic displays. In a non-trivial problem, valid features can't be selected and designed until the engineers have a very thorough knowledge of the signal characteristics of each class, and optimally a thorough understanding of the physics behind these characteristics. This in-depth knowledge of the data should allow the design of a reasonable segmentation algorithm and criterions. To gain this required information, signal waveforms were recreated and displayed on interactive
graphics devices, such as the CDC 1704 Digigraphics Display and the Tektronics 4002A Graphics Terminal. Estimates of the energy spectrum, using the Fast Fourier Transform, were computed and displayed. Displays and hardcopies of these waveforms and their power spectrums were the tools which enabled the designers to view and analyze the behavior of each class of seismic waveforms.

Since data segmentation in the real intrusion detection system will probably be done at the sensor, simplicity and efficiency are of utmost importance. The procedure decided upon begins with calculating the mean value of the entire run, then subtracting that mean from the run (realizable in the field by appropriate capacitive coupling in the sensor's analog output) to eliminate any DC bias. The signal is then full-wave rectified. The average value of each second of the rectified signal is then computed, and a segment of valid data is defined as one for which this one-second average exceeds some threshold $\theta$ for five consecutive seconds.

Symbolically, given the samples $f_i$ of a complete intrusion run, the average absolute value, $S_k$, will be calculated for each consecutive one-second window.
\[ S_k = \frac{1}{n} \sum_{i=1}^{n} |f_{nk+i} - \hat{m}|, \text{ for the } k\text{th second} \]

where \( k = 0, 1, \ldots, L-1 \)

\( L = \text{the number of seconds in the run} \)

\( \hat{m} = \frac{1}{N} \sum_{i=1}^{N} f_i = \text{the estimated mean of the run} \)

\( n = \text{number of samples per one second window and} \)

\( N = \text{number of samples in complete run} \)

Segment and save the data in the five second interval if and only if \( S_k \) is greater than the threshold \( \theta \) for five consecutive one second windows.

Obviously, strong signals, from either large sources or intrusions near to sensors, will result in a greater number of five-second segments. This is desirable, since these stronger signals represent a better signal-to-noise ratio.

The specific segment lengths and thresholds were based on observation and experimentation. The five-second length precluded the acceptance of spurious bursts of noise or brief signal transients as good data. Also, the second-by-second threshold requirement during the five seconds assured that the entire segment was sufficiently strong, instead of having brief but significant lapses into noise. The possibility of triggering this classifier with impulsive noise,
such as explosions, gun-fire, etc. is not likely unless the noise were highly repetitive and sustained over a five second interval.

The threshold, however, required the collection of some statistics. The objective was a threshold which would overlook as much noise as possible, yet which would locate as much valid intrusion data as possible. We selected three representative runs from each data class (including strictly noise runs) and compiled tables of the total time segmented from each run by a variety of thresholds. We then observed, via graphics, the five-second segments selected by thresholds of 20, 30, and 40, and decided that \( \theta = 20 \) afforded the best balance between noise rejection and significant data segmentation.
SECTION IV
DATA ANALYSIS

Classifier design requires the analysis of graphic representations of digitized waveforms and their transforms for the purpose of hypothesizing measurements or features which may aid in the discrimination of target classes. This is one of the most important steps in the waveform classification problem because the quality of the selected features directly influences the classifier's performance.

Before data analysis can begin, the researcher must develop or have access to a system which will display his data in some graphic form. At the start of ISCP's involvement in the sensor program, in-house personnel developed a waveform analysis software system on the CDC-1700/Digigraphics System. This waveform analysis tool enabled a user to randomly access and display waveforms or waveform segments and perform operations on the data, such as rectifying, integrating, measuring zero crossings, calculating power spectrums, etc. The major deficiency in this system was its lack of a hard copy capability. Unfortunately, shortly after this interactive graphics software system was operational, the CDC-1700/Digigraphics System was phased out.
Effort was redirected to develop a similar interactive capability on the Honeywell 635, using a remote storage tube terminal as the graphics console. Soon after this development started, it was evident that the development time required for an interactive system in the GECOS III multiprogramming environment was not compatible with the schedule for developing this classifier.

Pattern Analysis and Recognition Corporation (PAR) then made their sensor analysis facility [3] available for this effort.

PAR's sensor analysis facility is designed to analyze acoustic data and is built around a NOVA 800 computer with a 9-track tape unit, card reader, 128K word disk, and a Tektronix 4002A display with hardcopy.

Two software changes had to be made before we could use PAR's facility. First, the BAMKI data stripping program was modified to generate its output on the Honeywell 635's only available nine-track tape drive because the PAR facility's only tape drive was a nine-track unit. Second, PAR modified their system by adding a new input routine to it, which could read the nine-track version of our simplified data format.

Once we were able to process seismic data from a BAMKI tape, using PAR's facility, a production procedure was set
Three copies of the BAMKI tapes could be left to be processed at night by the 635. Since the Honeywell 635 has only one available nine-track tape drive, only one copy of the BAMKI stripping program was able to execute at a time. Often the BAMKI programs were delayed from executing for long periods of time because the 635’s only nine-track tape drive was previously assigned to long batch jobs.

Time domain waveforms and power spectrums for at least one complete run of each intrusion class variation were displayed and hardcopied at the sensor analysis facility. For ground vehicles, these class variations were the different vehicle velocities recorded along each of these paths. For aircraft, these class variations were the different altitudes of the flyovers and the different velocities recorded for each altitude. The class variations for humans were in the number of intruders, path of intrusion, and velocity (feet per second). Examples of time waveform and power spectrum hardcopies for each class are shown in Figures 1 thru 10.

After the hardcopies of the selected intrusion runs were generated, they were added to the hardcopy library. This library consisted of two note books, one containing the time domain waveforms and the other containing power spectrum plots.
A team of ISCP engineers analyzed the data plots contained in the hardcopy library. By comparing the various plots of the intrusion classes looking for within-class similarities and between-class differences, this team compiled a list of 48 potential features. One very useful data plot used in our analysis was the 40-line power spectrum in which each line represents the power spectrums of consecutive one-second windows. The representation of the data in this format enables the analyst to view and compare changes in the power spectrum throughout the duration of the intrusion. Examples of the 40-line power spectrum are shown in Figures 11 and 12. Figure 11 shows the 40-line power spectrum plot of a C-131 aircraft on a radial path over the test site. The frequency shift in the main peaks of the power spectrum indicates when the C-131 responses went through a doppler shift. A similar data display for the UH-1F helicopter, shown in Figure 12, indicates that the doppler shift is not as pronounced for the helicopter as it was for the C-131.
SAMPLE WAVEFORM OF AN ARMoured PERSONNEL CARRIER
FIGURE 4
SAMPLE POWER SPECTRUM OF AN M-109 TRUCK
FIGURE 8

SAMPLE POWER SPECTRUM OF A UH-1F HELICOPTER
SAMPLE WAVEFORM OF A C-131 AIRCRAFT
SAMPLE POWER SPECTRUM OF A C-131 AIRCRAFT
SECTION V

FEATURE DEFINITION

Several man-months of studying seismic waveforms on graphics and hardcopy displays produced a set of 24 features for consideration. These features were extracted from one-second (actually 1024 samples, or 1.024 seconds) segments of data and from five-second segments (5120 samples, 5.120 seconds) of data. The two different lengths were selected to evaluate the effect of segment length on classification success. The FFT routine required the number of samples used to be a power of two. Therefore, the one-second window size was chosen to contain 1024 samples instead of 1000. These 24 features taken over the two segment lengths produced a total of 48 features.

The rationale and definitions of the features are given below, in the order in which they appear in the vector data. That is, component 1 of the vector is the average \( \bar{R} \) for one second. Any DDC offset present was subtracted before all processing.

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<th>DEFINITION AND RATIONALE</th>
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<td>1.</td>
<td>( \bar{R} ) for one second (Average ( R ) for each half-second of a contiguous one-second segment): ( R ) is defined as the ratio of the maximum absolute signal amplitude during a half-second interval to the average absolute</td>
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DEFINITION AND RATIONALE (continued)

amplitude for that half second. This feature appeared a likely candidate for distinguishing the class of humans, whether one or several, walking or running. The impact of a heel gives a sharp, strong spike in the signal, which decays to noise level considerably before the next heel impact. This effect produces a significantly higher value of R than does a vehicle or aircraft, since the latter usually produces high spikes only when the signal is strong enough to produce a high RMS value.

2. $\bar{R}^2$ for one second (average $R^2$ for the two half seconds): Although any information contained in R (e.g., a threshold) will map uniquely into $R^2$, squaring R made the distinction between humans and all other classes more obvious to the operator, and eventually to OLPARS.

3. $\bar{R}$ for five seconds (average $R$ for 10 contiguous half-second segments).

4. $\bar{R}^2$ for 5 seconds.
5. Harmonic spacing for one second (the most frequently occurring pairwise spacing between the six largest peaks in the power spectrum above 40 Hz): This feature was suggested by the evenly spaced harmonics that were evident in aircraft waveforms.

6. Harmonic occurrences in one second (the number of times that the spacing of component 5 above occurred in the one second spectrum): The C-131 usually evidenced harmonics at 20-Hz intervals, the UH-1F helicopter at 12.5 Hz intervals.

7. The ratio of the energy between 1 and 20 Hz to that between 21 and 40 Hz for one second (hereafter symbolized by: $E_{1-20}/E_{21-40}$): Although the jeep and APC spectra overlapped considerably, the jeep spectrum did extend somewhat lower than the APC spectrum, which usually dropped off below 20 Hz.

8. $E_{41-60}/E_{21-40}$ for one second: An attempt to separate trucks from APCs.
9. The number of points in the one second power spectrum which are below 25% of the maximum:
   A coarse amplitude histogram was taken to estimate the value of amplitude information.

10. The number of points in the one second power spectrum which are >25% and <50% of the maximum.

11. Number as in 9 and 10 of points >50% and <75%.

12. Number of spectral points >75% of maximum.

13. The ratio of the energy above 100 Hz to that below in the one-sec. power spectrum (i.e. $E_{101-511}/E_{1-100}$): Aircraft tend to produce more energy above 100 Hz than do any other classes.

14. $E_{1-5}/E_{1-60}$ for the first second: To estimate the value of spectral distribution information.

15. $E_{6-10}/E_{1-60}$, first second.

16. $E_{11-15}/E_{1-60}$, first second.

17. $E_{16-20}/E_{1-60}$, first second.

18. $E_{21-25}/E_{1-60}$, first second.

19. $E_{26-30}/E_{1-60}$, first second.

20. .
DEFINITION AND RATIONALE (continued)

25. \( E_{56-60}/E_{1-60} \), first second.

26. The number of peaks in the first one second power spectrum which exceed 10% of the maximum peak.

27. Harmonic spacing for the 5-second ensemble average of 5 successive one-second power spectra (see No. 5).

28. The number of times the spacing of No. 27 occurs in the 5-second ensemble average (see no. 6).

29-48. Components 29-48 are extracted just as components 7-26, in that sequence, except that the spectra observed consist of an ensemble average of 5 consecutive one-second power spectra instead of a single one-second spectrum.
Once the list of 48 features had been compiled, a batch program was written for the Honeywell 635 to extract these features from the unpacked data tapes. This batch program consists of the main "control" program, a Fast Fourier Transform (FFT) subroutine, a double up algorithm, and a number of feature extraction subroutines.

Data cards direct the control program as to which and how many runs and channels are to be processed. The control program then monitors the specified input data tape channels and calls the feature extraction subroutines when the monitored data channel satisfies the automatic segmentation criteria. The first subroutines called extract features from the time domain waveform segment in the data array X. After these features are extracted, the double up algorithm is called three times to help calculate five consecutive one-second power spectra of the data in X. Since the waveform segments do not have an imaginary component, the double up algorithm enables the FFT to calculate two power spectra with one call to subroutine DOUBLE. After the power spectra are returned, their ensemble average is computed.
The X array will then contain two power spectra of interest, the spectrum for the 1st second and the average spectrum for the five seconds of data. The subroutines which extract features from these two power spectra are then called. After all the feature extraction subroutines are called, a labeled feature vector is punched out on cards.

After completion of the feature extraction program, the output data deck is taken to the CDC-1604B computer where the feature vectors are transferred to an OLPARS compatible tape.

Listings of the feature extraction program and its subroutines are provided in Appendix A.
The first step in using the On-Line Pattern Analysis and Recognition System (OLPARS) is to evaluate the discriminatory quality of the extracted features. This enables us to use fewer measurements to achieve a satisfactory classifier design. The OLPARS provides two suboptimal methods for ranking the discriminatory power of the extracted features. Each of these methods provides three types of rankings. The first type uses a significance measure of a particular feature, $X_p$, for discriminating class $i$ from class $j$ and is designated by $M_{ij}(X_p)$. The second type of ranking uses a significance measure of $X_p$ for discriminating class $i$ from all other classes and is designated $M_i(X_p)$. The last type uses a measure of the overall significance of $X_p$ for discriminating all classes and is designated $M(X_p)$.

The first method in OLPARS for ranking features is the discriminant measure, which is particularly useful when the class conditional probability distributions are unimodal. These discriminant measures, using feature $X_p$, are defined as follows:
\[ M_{ij}(X_p) = \frac{\left[ \bar{x}_p^{(i)} - \bar{x}_p^{(j)} \right]^2}{(N_i - 1) \left[ \hat{\sigma}_p^{(i)} \right]^2 + (N_j - 1) \left[ \hat{\sigma}_p^{(j)} \right]^2} \]

\[ M_i(X_p) = \sum_{j \neq i}^K M_{ij}(X_p) \]

\[ M(X_p) = \sum_{i=1}^K M_i(X_p) = \sum_{i=1}^K \sum_{j \neq i}^K M_{ij}(X_p) \]

where \( \bar{x}_p^{(j)} \) = the estimated mean of class \( j \) along measurement \( X_p \).

\( \hat{\sigma}_p^{(j)} \) = the estimated standard deviation of class \( j \) along measurement \( X_p \).

\( N_j \) = the number of samples from class \( j \).

The other OLPARS feature evaluation method is the probability of confusion measure. It is valid for any probability distribution since it essentially measures the overlap of the class conditional probabilities.

Since the functional forms of the class conditional probabilities are not known, OLPARS estimates the marginal class distributions using the sample data. The range for feature \( X_p \) is divided into cells of width \( \Delta \). The probability that a sample from class \( j \) will occupy the \( y \)th cell along the range of feature \( X_p \) is given by:
The probability of confusion measures using feature \( x_p \)
are defined as follows:

\[
M_{ij}(x_p) = 1 - \left[ \sum_{j=1}^{N_p} \prod_{i=1}^{M} \left( P_{ij}(i) \cdot P_{ij}(j) \right) \right]
\]

\[
M_i(x_p) = \sum_{j=1}^{K} M_{ij}(x_p)
\]

\[
M(x_p) = \sum_{i=1}^{K} M_i(x_p) = \sum_{i=1}^{K} \sum_{j \neq i} M_{ij}(x_p)
\]

where \( N_p \) = the number of cells along measurement \( x_p \)
and \( K \) = the number of classes.

The ranking of extracted features based on these evaluation techniques provides the information required to rationally choose initial subsets of the 48 features for logic design. Logic design is an iterative process in which many designs, based on modified versions of the initial feature subsets, are generated and tested. Features which appear to discriminate between the more troublesome classes are added, while superfluous features which rank high for
the same easily discriminated classes are eliminated.

For this five-class problem, the top fifteen features, rank-ordered by the probability of confusion measure, $M_{ij}(X_p)$, are shown in Appendix B.
The classifiers designed by ISCP for this pattern recognition problem consist solely of sets of linear discriminants for ease of hardware implementation. The logic for these classifiers is based on the pairwise Fisher Linear Discriminant Technique. For each pair of classes i and j, a unit vector $d_{ij}$ is computed such that projections of the data onto $d_{ij}$ maximize the ratio of the between-class scatter to the within-class scatter. The direction $d_{ij}$ which maximizes this ratio is given by Reference [5].

$$d_{ij} = \alpha W_{ij}^{-\frac{1}{2}} \tilde{A}_{ij}$$

where

$$W_{ij} = (N_i - 1) C_i + (N_j - 1) C_j$$

$C_{ij}$ = Estimated covariance matrix for class i

$$\tilde{A}_{ij} = \tilde{\mu}_i - \tilde{\mu}_j$$

$\tilde{\mu}_i$ = Estimated mean vector of class i

$N_i$ = Number of vectors in class i

and $\alpha$ is a normalizing constant so that $|d| = 1$. 
OLPARS computes $d_{ij}$ and an initial threshold, $\Theta_{ij}$, to
distinguish between all pairs of classes. These thresholds
may be adjusted, if necessary, to obtain optimal discrimina-
tion along each $d_{ij}$:

For example, the inner product of an unknown input
feature vector, $\chi$, is taken with the discriminant $d_{AH}$ for the
pair of APCs and helicopters, compared with the threshold
$\Theta_{AH}$ for the pair of APCs and helicopters.

$$\text{If } \langle d_{AH}, \chi \rangle = \sum_{i=1}^{K} x_i d_{AH} > \Theta_{AH} \text{ increment the counter}$$
for the APC class.

$$\text{If } \langle d_{AH}, \chi \rangle = \sum_{i=1}^{K} x_i d_{AH} < \Theta_{AH} \text{ increment the counter}$$
for the helicopter class.

$$\text{If } \langle d_{AH}, \chi \rangle = \sum_{i=1}^{K} x_i d_{AH} = \Theta_{AH} \text{ increment the counter}$$
for the class with the larger number of samples
in the design set.

where $K$ = Size of the feature space.

After all the pairwise decisions are made, a binary vote
is cast by each comparator and the final decision is deter-
mined by the class counter that received the most votes. In
case of ties, the decision is given to the class involved in
the tie which has the highest a priori probability. The re-
sultant classification scheme is diagrammed in Figure 13.
Figure 13.
SECTION IX
RECOGNITION RATES

Four classifiers were designed using 16, 22, 33, and 44 features. With the exception that feature 46 is missing from the 44 feature design, each design is based on a subset of the features used in the higher order designs. Figure 14 lists the features used for each design.

These classifiers were evaluated with the design data set and an independent test data set. The design set consisted of 715 vectors: 133 vectors from the class of helicopters; 176 for APCs; 135 for heavy trucks; 136 for humans; and 135 represented C-131s. The independent test set was comprised of 607 vectors: 159 for helicopters; 171 for APCs; 16 for heavy trucks; 129 for humans; and 132 for C-131s. The design and test confusion matrices from the resulting evaluation of each classifier are shown in Figures 15 thru 18.
### FEATURE LIST FOR EACH DESIGN

#### 44 FEATURE DESIGN

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#### 33 FEATURE DESIGN

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#### 16 FEATURE DESIGN

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<th>4</th>
<th>27</th>
<th>28</th>
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</tbody>
</table>

**FIGURE 14**

39
### Confusion Matrix for the Design Set

**Assigned Class**

<table>
<thead>
<tr>
<th></th>
<th>H</th>
<th>A</th>
<th>T</th>
<th>M</th>
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<tr>
<td>T</td>
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<td>2</td>
<td>133</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>M</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>133</td>
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Probability of Correct Classification = .973

**Confusion Matrix for the Test Set**

**Assigned Class**

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<tbody>
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</table>

Probability of Correct Classification = .848

**Legend:**
- H - Helicopter
- M - Human
- A - APC
- C - C-131
- T - Heavy Truck

**Figure 15**

40
### Confusion Matrix for the Design Set

**True Class**

<table>
<thead>
<tr>
<th>Assigned Class</th>
<th>H</th>
<th>A</th>
<th>T</th>
<th>M</th>
<th>C</th>
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<tbody>
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Probability of Correct Classification = .963

### Confusion Matrix for the Test Set

**True Class**

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</tr>
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</tbody>
</table>

Probability of Correct Classification = .856

### Legend:
- **H** - Helicopter
- **M** - Human
- **A** - APC
- **C** - C-131
- **T** - Heavy Truck

**Figure 16**

41
### CONFUSION MATRIX FOR THE DESIGN SET

**ASSIGNED CLASS**

<table>
<thead>
<tr>
<th></th>
<th>H</th>
<th>A</th>
<th>T</th>
<th>M</th>
<th>C</th>
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Probability of Correct Classification = .962

### CONFUSION MATRIX FOR THE TEST SET

**ASSIGNED CLASS**

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<th>T</th>
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<td>5</td>
<td>0</td>
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</table>

Probability of Correct Classification = .860

**LEGEND:**
- **H** - HELICOPTER
- **A** - APC
- **T** - HEAVY TRUCK
- **M** - HUMAN
- **C** - C-131

**FIGURE 17**

42
### Confusion Matrix for the Design Set

Using 16 Features

<table>
<thead>
<tr>
<th>Assigned Class</th>
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<th>T</th>
<th>M</th>
<th>C</th>
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<tbody>
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<td>4</td>
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<tr>
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<td>M 2</td>
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<td>0</td>
<td>129</td>
<td>4</td>
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*Probability of Correct Classification = .951*

### Confusion Matrix for the Test Set

Using 16 Features

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*Probability of Correct Classification = .853*

### Legend

- **H**: Helicopter
- **A**: APC
- **T**: Heavy Truck
- **M**: Human
- **C**: C-131

---

**Figure 18**

43
Note that the probability of correct classification using the design set increases monotonically as the number of features is increased; while using the test set, it reaches its maximum value for 22 features and drops off. Foley [2] points out a statistical trap involved with using the probability of error on the design as a measure of the true performance of the system when the ratio of the sample size to feature size is small. The probability of error or correct classification on the test set is the better measure and indicates that the probability of correct classification of 0.86 for the 22-feature design is the best performance.

The essential difference between the 22-feature design and the 16-feature design is that the former is based on measurements of both one and five second data segments, whereas, the latter is based solely on measurements of five second segments. Therefore, the exclusion of one second measurements not only reduces the dimensionality of the decision logic from 22 to 16, but it also simplifies feature extraction by elimination of the one second phase of the extraction process. The trade-off between the slightly superior performance of the 22-feature design (Pcc on the test set of 0.86) versus the simplicity and ease of implementation of the 16-feature design clearly
ranks the 16 feature design ahead of the 22-feature design.

The linear discriminants for the 16-feature logic design are given in Appendix C. These linear discriminants contain the ten weight vectors with their respective thresholds and, together, with the block diagram in Figure 13, completely define the pairwise Fisher logic for the 16-feature design.
SECTION X

DISCUSSION AND RECOMMENDATIONS

In many waveform classification problems, the classifier is designed entirely from features extracted from a waveform database which is representative of each class. To insure that the database is representative, data must be collected for a sufficient number of runs of each intrusion variation (speed, path, direction, etc.), so that the data for each variation is truly representative. Emphasis must be placed on the generality of a database and not on its size alone. For example, to design a classifier which will detect most trucks, the database must contain data from a wide variety of different type trucks, all operating at a number of sampled speeds and carrying loads which vary from maximum capacity to empty. The wider the variety of vehicles within a class, the more complex the data analysis becomes because all the variations and the possible combinations of the variations have to be sampled and analyzed for each variety of vehicles.

The main goal of this effort is the development of a seismic classifier which will satisfy an acceptable error criteria regardless of where the classifier is located. The seismometer response to an intrusion target is the signal which results from the convolution of the target signature.
with the impulse response of the earth. The earth's impulse responses differ greatly throughout the world because they are determined by the geology and terrain of the locale. These impulse responses or transfer characteristics are not necessarily constant between two points in a locality but may change periodically as a function of the seasonal variations. Seasonal variations in the transfer characteristics are caused by changes in either the height of the water table, the depth of the frost line, or amount of snow cover. Therefore, it may not be realistic to believe that one seismic logic design might perform satisfactorily in any location or for an extended period of time in a locality which has extreme seasonal variations.

The key to the general seismic classifier design problem is the discovery of waveform features which contain adequate discriminatory information and are invariant to geographical location and seasonal variation. This report does not shed any light on the theory that such features exist, but it does exercise the procedures required to determine their existence. The importance of the data collection and data analysis procedures cannot be over emphasized. Before data analysis can yield meaningful results, the data base must contain data collected from selected test sites which are representative of the various types of terrain, geology, and seasonal variations found throughout the world.
APPENDIX A

BATCH PROGRAM LISTINGS
PROGRAM TO STRIP SPECIFIED DATA CHANNELS FROM A BAN KI TAPE
AND WRITE A NEW TAPE WITH A SIMPLIFIED FORMAT.

C
C
C PROGRAM TO STRIP SPECIFIED DATA CHANNELS FROM A BAN KI TAPE
AND WRITE A NEW TAPE WITH A SIMPLIFIED FORMAT,
C
COMMON IDAT(320,?),JCOUNT(45)
COMMON/JAZZ/IA(1558),IEOF,IBORT,IPARTY
COMMON/JIM/LA(326)
COMMON/AVG/IAVG(45),LJCOUNT(45),JK,NTIMES,IPRINT
DIMENSION KCOUNT(45)
IPARTY=0
IBORT=0
JGROUP=0
READ 1001,NUM,(KCOUNT(J),J=1,NUM)
1001 FORMAT*(4012)
READ 1003,RECORD,NRECN,NTIMES
1003 FORMAT*(215)
READ 1001,IPRINT
DO 400 I=1,NUM
IN*KCOUNT(I)
WRITE(4,1006)I,IND
1006 FORMAT(10X,7HRECORD,12,17H IS FROM CHANNEL ,12)
400 LCOUNT(IND)=1
3 JCOUNT(J)=0
READ 1005,N=1,NREC
CALL SPWN(N,NUM,KCOUNT)
IF(IEOF,EQ.1) GO TO 1004
IF(IEOPT.NE.0) GO TO 1005
IF(JGROUP.NE.0) GO TO 1005
LO 1000 J=1,NUM
1A(I)=IDAT(I)
CALL PPRC
CONTINUE
1000 CONTINUE
1005 CONTINUE
1004 IF(JGROUP.EQ.0) GO TO 1007
IF(IEOPT.NE.0) GO TO 1007
DO 66 I=1,NUM
IND*KCOUNT(I)
KEND=JCOUNT(IND)
EO 66 J=KEND,320
66 IDAT(J)=0
LA(I)=IAVG(I)
LO 67 J=7,326
67 LA(J)=IDA(I-6,1)
65 CALL PPRC
1007 CALL WFF
CALL WFF
CALL WFF
STOP
END
SUBROUTINE SPAN( JPARM, NUM, KCOUNT)

COMMON/JIM/IA(32)
COMMON/JAZZ/IA(1656), IEOF, IBORT, IPARTY
COMMON/<DAT(32), J), JCOUNT(j)
COMMON/AVG/E/AVG(45), JCOUNT(j), JK, TIMES, IPRT
DIMENSION ION(4), JON(32), JP(14)
DIMENSION KCOUNT(j), MASK(3), KONST(3)
DIMENSION FAVG(45)
DATA ITAIL/252144/
DATA (JP(j), I=1,14)/1,21,1,12,22,39,1,12,1,3,17,1,30,1,12/
DATA KM/0.777777777000/
DATA (MASK(1), I=1,3)/0.777777777000,0.000000000777777/
DATA (KONST(1), I=1,3)/16777216,4096,1/
DATA MASKA, MASKB/0.777777777000,0.000000000777777/
FORMAT(B(2x,12))
CALL RFL
IF(IEOF,E,0) RETURN
IF(JFARM,E,1) GO TO 2
LA(3)=AND(IA(2), MASKA)/THALF
LA(4)=AND(IA(2), MASKB)
ISAMP=TIMES
TIMES=1000/ISAMP
RECODE=0.
2 IOU(1)=AND(IA(1), MASKA)/THALF
IOU(2)=AND(IA(1), MASKB)
IOU(3)=AND(IA(2), MASKA)/THALF
IOU(4)=AND(IA(2), MASKB)
IF(LA(4).EQ.100) GO TO 7
IF(LA(3).EQ.100) GO TO 5
IF(IHORT)6,19,10
5 IF(IHORT)6,8,5000
6 CALL BFS
CALL WEF
IFORT=1
GO TO 5000
7 IF(LA(3).EQ.100) GO TO 11
IF(IHORT)6,19,10
11 IF(IHORT)6,19,10
19 IF(IJK, IG, 0) GO TO 9
DO 65 IE=1, NUM
INO=KCOUNT(I)
KEN=JCOUNT(INO)
DO 66 J=KEN+320
66 IDAT(J,1)=0
LA(4)=IAVG(1)
DO 67 J=7,12A
67 LA(J)=IDAT(J-6,1)
65 CALL PROF
GO TO 9
12 CALL BFS

50
CALL WFF
10 IBORT=0
   RECORD=0.
   IJK=I
9
LA(I)=I0D(I)
LA(2)=ISAMP
LA(3)=I0D(3)

LAG=C=I0D(4)
LA(5)=AND(IA(228),MASKP)
LA(6)=ANH(IA(229),MASKA)/IHAF-40
IF(LA(6).GE.0) GO TO 3
LA(5)=LA(5)-1
LA(6)=1000*LA(6)

3 IF(IJK,GT,0) GO TO 444
   DO 50 J=1,NUMH
      INDP=COUNT(J)
444 IC=2
50
DO 160 MM=1,8
   DO 800 K=1,9,2
      JBE=JP(K)
51      JPE=JP(K+1)
         M=0
52      IC=IC+1
         DO 400 J=JBE,JPE
            M=M+1
53         IF(M,LT,4) GO TO 401
         IC=IC+1
         TO 400
401 IF(JCOUNT(J),EQ,0) GO TO 400
         I=AND(IA(11),MASK(M))
         I=I/KONST(M)
         IF(I,GE,2048) I=OR(I1,KM)
         J=JCOUNT(J)
         I=LCOUNT(J)
         JDAT(J,J)=I
         JCOUNT(J)=JCOUNT(J)+1
         CONTINUE
   IF(MK-2)600,700,800
600 JBE=JP(11)
      JPE=JP(12)
      GO TO 402
700 JBE=JP(13)
      JPE=JP(14)
402 M=0
         IC=IC+1
9         DO 510 J=JBE,JPE
            M=M+1
510      IF(M,LT,4) GO TO 501
         IC=IC+1
         M=1
IF(JCOUNT(J),EQ.0) GO TO 500

I1=AND(IAT(I),MASK(M))
II=I1/KONST(M)
IF(II.GE.2048) I1=OR(I1,KM)
J1=JCOUNT(J)
L1=JCOUNT(J)
IDAT(J1,L1)=I1

JCOUNT(J)=JCOUNT(J)+1
CONTINUE
800 CONTINUE
NNP=4*NN
NN4=NNP-3
GO 900 KZ=NN4,NNP,2
IC=IC+1
KZP=KZ+1
JOD(KZ)=AND(IAT(1C),MASKA)/IMAHF
JOD(KZP)=AND(IAT(1C),MASKB)

900 IC=IC+5
IF(1PRINT,EQ.0) GO TO 44
WRITE(6,45)(JOD(I),I=1,N)
45 FORMAT(120,4(2X,C10))
WRITE(6,46)(JOD(I),I=1,N)
46 FORMAT(10X,012.2,2X,01)
64 IJK=1
DO 5001 I=1,NUM
IF(JK_.NE.,NTIMES) GO TO 20
JK=C
RECORD=RECORD+1,
LO 48 M=1,NUM
FMEAN=0,
GO 60 J=1,320
FDAT(IDAT(J,M)
FAVG(M)=FAVG(M)+M,N
FAVG(M)=FAVG(M)+FMEAN/RECORD
WRITE(6,47) FMEAN,FAVG(M)
47 FORMAT(10X,14HRECORD MEAN = ,F12.4, 16H PARTIAL MEAN = ,F12.4)

48 IF(IPARTY,NE.,1) GO TO 5001
IND*KCOUNT(I)
WRITE(6,111) IND
111 FORMAT(5X,4HCHANNEL ,12)
KEND=JCOUNT(IND)-1
WRITE(6,40)(IDAT(J,I),J=1,KEND)
5001 CONTINUE
IPARTY=0
5000 RETURN
END

23799 WORDS OF MEMORY USED BY THIS COMPILATION
<table>
<thead>
<tr>
<th>1</th>
<th>LBL</th>
<th>SUBROUTINE TO READ RAMKI TAPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>SYMDEF</td>
<td>BELLRD</td>
</tr>
<tr>
<td>3</td>
<td>SYMREF</td>
<td>BSF</td>
</tr>
<tr>
<td>4</td>
<td>BLOCK</td>
<td>JAZ7</td>
</tr>
<tr>
<td>5</td>
<td>JZ</td>
<td>BSS 1859</td>
</tr>
<tr>
<td>6</td>
<td>IBORT</td>
<td>BSS</td>
</tr>
<tr>
<td>7</td>
<td>IPARTY</td>
<td>BSS 1</td>
</tr>
<tr>
<td>8</td>
<td>USE</td>
<td>PREVIOUS</td>
</tr>
<tr>
<td>9</td>
<td>BELLRD</td>
<td>SAVE</td>
</tr>
</tbody>
</table>

```
000000  000002710000  010
000001  000005630000  010
000002  000005754000  010
000003  000005741000  010
000004  777776235007  000  10  LDA    #2,01
000005  000003755000  010  11  STA    STR
000006  000001001000  000  12  MME    GENOS
000007  050000000000  000  13  RTB
000008  000003000000  011  14  ZERO   FC,DCW
000009  000003300000  010  15  ZERO   STR
000010  000002601000  000  16  MME    GERAD
000011  000003300000  010  17  LDA    STR
000012  000004037500  010  18  ANA    #000000000000
000013  000004111900  010  19  CMPA   #000000000000
000014  000002360000  010  20  TZE    ABORT
000015  000004211900  010  21  CMPA   #000000000000
000016  000002660000  010  22  TZE    EOF
000017  000002360000  010  23  LDA    #0,01
000018  000002771000  010  24  TRA    RETURN
```

**END OF BINARY CARD SUBROUTI**

```
000023  000001235007  000  25  ABORT  LDA   #1,01
000024  013504755000  030  26  STA    IPARTY
000025  000003071000  010  27  TRA    RETURN+1
000026  000006123500  07  000  28  TZE    EOF  LDA  #1,01
000027  013504755000  030  29  RETURN  STA   JZ+1858
000028  000001716000  010  30  RETURN  BELLRD
000029  000000000001  000  31  FC    BCI-   1,000001
000030  010000035020  030  32  DCW    IOD   JZ+1858
```

**ERROR LINKAGE**

```
000035  900000000000  000
000036  222543435124  000
```

**LITERALS**

```
000040  070000000000  000
000041  030000000000  000
000042  040000000000  000
```

**END OF BINARY CARD SUBROUTI**

```
34 END
```

43 IS THE NEXT AVAILABLE LOCATION.
<table>
<thead>
<tr>
<th>LBL</th>
<th>SUBROUTINE TO WRITE OUTPUT TAPE (7 TRACK VERSION)</th>
</tr>
</thead>
<tbody>
<tr>
<td>000000</td>
<td>SYMDEF PROC, WEF, RSF</td>
</tr>
<tr>
<td>000000</td>
<td>BLOCK JIM</td>
</tr>
<tr>
<td>000000</td>
<td>JZ BSS 326</td>
</tr>
<tr>
<td>000000</td>
<td>USE PREVIOUS</td>
</tr>
<tr>
<td>000000</td>
<td>PROC SAVE 0.1</td>
</tr>
<tr>
<td>000000</td>
<td>000041</td>
</tr>
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<td>000000</td>
<td>000042</td>
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</tr>
<tr>
<td>000000</td>
<td>000051</td>
</tr>
<tr>
<td>000000</td>
<td>000052</td>
</tr>
</tbody>
</table>

END OF BINARY CARD SUBROUTI
ERROR LINKAGE

000033 000000000000 000
000034 475146636270 000

END OF BINARY CARD SUBROUTI 49 END

336 IS THE NEXT AVAILABLE LOCATION,
GMAP VERSION/ASSEMBLY DATES JMPA 110171/102971 JMPB 110171/102971
THERE WERE NO WARNING FLAGS IN THE ABOVE ASSEMBLY
<table>
<thead>
<tr>
<th>LBL</th>
<th>SUBROUTINE TO WRITE OUTPUT TAPE (9 TRACK VERSION)</th>
</tr>
</thead>
<tbody>
<tr>
<td>000000</td>
<td>SYMDEF PROC,HETF,BSF</td>
</tr>
<tr>
<td>000001</td>
<td>BLOCK JMH</td>
</tr>
<tr>
<td>000002</td>
<td>J2 HSS 3PA</td>
</tr>
<tr>
<td>000003</td>
<td>USE PREVIOUS</td>
</tr>
<tr>
<td>000004</td>
<td>PROC SAVE</td>
</tr>
<tr>
<td>000005</td>
<td>LDX0 LDX1 0,0,DU</td>
</tr>
<tr>
<td>000006</td>
<td>TPL G01</td>
</tr>
<tr>
<td>000007</td>
<td>SPQ #1,DL</td>
</tr>
<tr>
<td>000008</td>
<td>GO1 QLS 20</td>
</tr>
<tr>
<td>000009</td>
<td>LSS 18</td>
</tr>
<tr>
<td>000010</td>
<td>ADX0 #1,DU</td>
</tr>
<tr>
<td>000011</td>
<td>TPL G02</td>
</tr>
<tr>
<td>000012</td>
<td>SRQ #1,DL</td>
</tr>
<tr>
<td>000013</td>
<td>QLS 20</td>
</tr>
<tr>
<td>000014</td>
<td>QLS 18</td>
</tr>
<tr>
<td>000015</td>
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<td>STA IA,1</td>
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<td>ADD1 #1,DU</td>
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<tr>
<td>000024</td>
<td>CMPX1 #163,DU</td>
</tr>
<tr>
<td>000025</td>
<td>TQN LOOP</td>
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<td>000026</td>
<td>MME G01NOS</td>
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<td>000027</td>
<td>LDB ZERO</td>
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<td>SF,DCW</td>
</tr>
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<td>000029</td>
<td>ZERO STR</td>
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<td>000030</td>
<td>MPE G01NOS</td>
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<td>000031</td>
<td>LDA DCW1</td>
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</tr>
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</tr>
<tr>
<td>000035</td>
<td>STA DCW1</td>
</tr>
<tr>
<td>000036</td>
<td>LDX1 #0,DU</td>
</tr>
<tr>
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<td>LOOP9 QLS 20</td>
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<tr>
<td>000038</td>
<td>QLS 20</td>
</tr>
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<td>000039</td>
<td>LSS 16</td>
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<tr>
<td>000040</td>
<td>QLS 20</td>
</tr>
<tr>
<td>000041</td>
<td>LOOP1 QLS 20</td>
</tr>
<tr>
<td>000042</td>
<td>LSS 16</td>
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<td>000043</td>
<td>QLS 20</td>
</tr>
<tr>
<td>000044</td>
<td>LOOP1 QLS 20</td>
</tr>
<tr>
<td>000045</td>
<td>LSS 16</td>
</tr>
<tr>
<td>000046</td>
<td>LOOP2 QLS 20</td>
</tr>
<tr>
<td>000047</td>
<td>QLS 20</td>
</tr>
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<td>000048</td>
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</tr>
<tr>
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<td>LSS 12</td>
</tr>
<tr>
<td>000053</td>
<td>LSS 12</td>
</tr>
</tbody>
</table>
ERROR LINKAGE

650 IS THE NEXT AVAILABLE LOCATION.

GMAP VERSION/ASSEMBLY DATES JMPA 110171/102971 JMPB 110171/102971

THERE WERE NO WARNING FLAGS IN THE ABOVE ASSEMBLY
SEISMIC SENSOR DATA FEATURE EXTRACTOR

NINE TRACK MAGNETIC TAPE VERSION

ICHAN IS THE MAXIMUM NUMBER OF DATA CHANNELS TO BE PROCESSED
NRUNS IS THE NUMBER OF RUNS TO BE PROCESSED IN THE NEXT PASS,
ITRESH IS THE THRESHOLD VALUE FOR THE ABSOLUTE AVERAGE DEVIATION
FROM THE MEAN FOR EACH 1,024 SECOND WINDOW,
IRUN IS AN ARRAY CONTAINING THE RUN NUMBERS TO BE PROCESSED IN
THE NEXT PASS,
ICHAN IS AN ARRAY CONTAINING THE CHANNEL NUMBERS TO BE PROCESSED
FOR EACH RUN IN THE NEXT PASS,
DIMENSION JHEAD(6), IBUF(6144), JTAIL(6), ITEMP(9), ICHAN(20), IRUN(20)
DIMENSION X(6144), FEAT(100)
EQUIVALENCE (X, IBUF), (JHEAD(7), IBUF(1))
IFC = 1
READ(5, 100) NCHAN
DO 21 ICHAN = 1, NCHAN
READ(3, 1000) NRUNS, ITRESH
1000 FORMAT (2IS5)
READ(5, 1001) (IRUN(I), I=1, NRUNS)
1001 FORMAT (4002)
READ(5, 1003) (ICHAN(I), I=1, NRUNS)
1003 FORMAT (4042)
WRITE(6, 1004) NRUNS, ITRESH
1004 FORMAT (1H0, 1X, 7HRUNS =, 3X, 3X, 8BITTRESH =, 15)
WRITE(6, 1008) (IRUN(I), I=1, NRUNS)
1008 FORMAT (1H0, 1X, 4HRUNS =5X, 16(2X, 02))
WRITE(6, 1012) (ICHAN(I), I=1, NRUNS)
1012 FORMAT (2X, 8CHANNELS, 1X, 16(2X, I2))
CALL RER
DO 20 I = 1, NRUNS
20 NYE= 0
1 CALL RD9(JHEAD(1), ICHAN(I), 0, 0, IFC, IEOF)
IF (IEOF .NE. 0) GO TO 1
IF (JHEAD(3), EQ, IRUN(I)) GO TO 2
CALL PSF
GO TO 1
2 ISTAI = 321
JSTART = 1
3 ISHIFT = 0
DO 40 J = ISTART, 5120, 320
IF (J .EQ. 1) GO TO 31
DO 30 II = 1, 6
JII = J + II
30 ITEMP(II) = IBUF(JII)
31 CALL RD9(IBUF(J-6), ICHAN(I), 0, 0, IFC, IEOF)
IF (IEOF .NE. 0) GO TO 20
IF (J .EQ. 1) GO TO 40
DO 4 II = 1, 6
4 CONTINUE
59
01  04-04-73  97,796  SEISMIC SENSOR DATA FEATURE EXTRACTOR

NINE TRACK MAGNETIC TAPE VERSION

JIJ=J*IJ=7
JTAIL(IJ)=IBUF(JIJ)
4 IBUF(JIJ)=ITEMP(IJ)
40 CONTINUE
DO 6 J=JSTART,5120,1024
L=J+1023
MEAN=JTAIL(J)
JSUM=0
DO 5 K=J,L
5 ISUM=JSUM+ABS(IBUF(K)-MEAN)
JSUM=JSUM/1024
PRINT 2001,JSUM
2001 FORMAT(10X,20I5)
IF(JSUM.GE.ITRESH) GO TO 6
ISHIFT=1
6 CONTINUE
JTAIL(5)=JTAIL(5)=6
JTAIL(6)=JTAIL(6)=800
IF(JTAIL(6).GE.0) GO TO 81
JTAIL(6)=1000*JTAIL(6)
JTAIL(5)=JTAIL(5)=1
81 PRINT 1005,JTAIL,ICHA(N(I))
1005 FORMAT(1X,012,2X,15,2X,012,2X,4(15,2X))
IF(ISHIFT.GE.0) GO TO 8
I=1
JSTART=I
1 IF(ISHIFT.GE.5120) GO TO 70
IDIF=5120-ISHIFT
JSTART=JSTART-IDIF/1024
ISHIFT=ISHIFT/320
ISHIFT=5121-(ISHIFT*320)
DO 7 J=ISHIFT+5120
IBUF(JJ)=IBUF(J)
7 JJ=JJ+1
70 JSTART=JJ
GO TO 3
8 DO 100 J=1,5140
100 X(J)=IBUF(J)
L=1
SUM1=0.
SUM2=0.
DO 10 J=1,1024,512
CALL ESGAR(X(J),X(5121),R)
SUM1=SUM1+R
10 SUM2=SUM2*R
FEAT(L)=SUM1/2.,
L=L+1
FEAT(L)=SUM2/2.,
L=L+1

60
DO 11 J=1025,5120,512
CALL RSQAR(X(J),X(5121),R)
SUM1=SUM1+R
SUM2=SUM2+R
FEAT(L)=SUM1/10.
L=L+1
FEAT(L)=SUM2/10.
L=L+1
L1=1
L2=4046
DO 200 J=1,3
M=2*(J/3)
CALL DOUBLE(X(L1),X(L2),M)
L1=L1+2048
L2=L2+2048
9 X(J)=X(J-512)+X(J)+X(J-536)+X(J-2048)+X(J+384))/5.
CALL HARMON(X,6,40,4,FEAT(L),FEAT(L+1))
L=L+2
CALL BIBMAT(X,2,FEAT(L),FEAT(L+1))
L=L+2
CALL THRESH(X,2,4,FEAT(L))
L=L+4
CALL SPECVT(X,12,101,FEAT(L),FEAT(L+12))
L=M+13
CALL PEKPIK(X,2,0,1,FEAT(L))
L=M+1
CALL HARMON(X(513),6,40,4,FEAT(L),FEAT(L+1))
L=M+2
CALL BIBMAT(X(513),2,FEAT(L),FEAT(L+1))
L=L+2
CALL THRESH(X(513),2,4,FEAT(L))
L=L+4
CALL SPECVT(X(513),12,101,FEAT(L),FEAT(L+12))
L=M+13
CALL PEKPIK(X(513),2,0,1,FEAT(L))
PRINT 2000,(FEAT(IND),IND=1,L)
FORMAT(10X,10E10,3)
PUSH 1005,STAIX,ICHAN(I)
M=1
DO 12 J=1,L,6
L=L+1
IF(L.GT.L1) L1=L
PUSH 2002,(FEAT(IND),IND=J,L1),M
2002 FORMAT(6E12,4,IX)
12 M=M+1
NYECT=NYECT+1
ISTART=1
J=J+1
GO TO 3

61
SEISMIC SENSOR DATA FEATURE EXTRACTOR

NINE TRACK MAGNETIC TAPE VERSION

01 04-04-73    17,796 SEISMIC SENSOR DATA FEATURE EXTRACTOR

20 PRINT 2003, VECT
2003 FORMAT(20H TOTAL VECTORS = 5, 10)
21 CALL NEW
STOP
END

THE TOP DOES NOT APPEAR IN READ, DATA, COMMON OR LEFT OF EQUALS (=)

THE MID DOES NOT APPEAR IN READ, DATA, COMMON OR LEFT OF EQUALS (=)

THE BOTTOM DOES NOT APPEAR IN READ, DATA, COMMON OR LEFT OF EQUALS (=)

23842 WORDS OF MEMORY USED BY THIS COMPILATION
SUBROUTINE DOUBLE(X,Y,NUM)
C
THIS SUBROUTINE ENABLES THE CALCULATION OF THE
POWER SPECTRUMS OF TWO REAL WAVEFORM SEGMENTS
C
WITH ONE CALL TO THE FFT SUBROUTINE.
DIMENSION X(1024), Y(1024), S1(1024), S2(1024), TAB(780)
IF(NUM=1) 30, 25, 30
25  DO 27 J=1, 1024
27  Y(J)=0
30  CALL FFT(1024, 1.0, X, Y, S1, S2, TAB)
IF(NUM=1) 285, 400, 285
285  DO 300 K=2, 512
290  L=1024-K
291  A=X(K)*X(L)
292  B=X(K)*X(L)
293  C=Y(K)*Y(L)
294  D=Y(K)*Y(L)
295  X(K)=(A*B-D*B)*.25
300  Y(K)=(C*B+B*C)*.25
301  X(1)=0
302  X(513)=0
303  DO 320 K=2, 512
320  X(K)=Y(K)
321  RETURN
400  DO 450 K=2, 512
450  X(K)=A+B
451  X(1)=0
452  RETURN
END

S1 DOES NOT APPEAR IN READ, DATA, COMMON OR LEFT OF EQUALS (=)
S2 DOES NOT APPEAR IN READ, DATA, COMMON OR LEFT OF EQUALS (=)
TAB DOES NOT APPEAR IN READ, DATA, COMMON OR LEFT OF EQUALS (=)

23721 WORDS OF MEMORY USED BY THIS COMPILATION
SUBROUTINE FFT(NSTAGE, SIGN, XR, XI, SCRAT1, SCRAT2, SCRAT3)

ALBERT H. PROCTOR 21 JANUARY 1972 HONEYWELL 635 FORTRAN IV

NSTAGE IS THE LOG BASE 2 OF N WHERE N IS THE NUMBER OF DATA POINTS

TO BE PROCESSED.

SIGN IS THE TRANSFORM/INVERSE TRANSFORM FLAG.

SIGN IS -1, FOR THE TRANSFORM AND 1, FOR THE INVERSE TRANSFORM.

XR WILL CONTAIN THE REAL PART OF EITHER THE INPUT OR OUTPUT DATA.

XI WILL CONTAIN THE IMAGINARY PART OF EITHER THE INPUT OR OUTPUT DATA.

SCRAT1 AND SCRAT2 ARE SCRATCH ARRAYS OF LENGTH N.

SCRAT3 CONTAINS THE COSINE TABLE OF LENGTH 3/4 N.

DIMENSION XR(2), XI(2), SCRAT1(2), SCRAT2(2), SCRAT3(2)

DATA NSTAGE/0/

IF (SIGN) 12, 11, 11

11  ASSIGN 6 TO ISIGN

GO TO 13

12  ASSIGN 7 TO ISIGN

GO TO 13

13 IF (NSTAGE - NSTAGE) 14, 5, 14

14 NSTAGE=NSTAGE

N=2**NSTAGE

N2=N/2

PHI2N=6.2831853/PLTN

NPI=N2+1

NPI1=NPI+1

N4=N/4

NPI2=N4+1

N3PI2=3*N4+1

SCRAT3(1)=1.

SCRAT3(NPI2)=0.

SCRAT3(NPI)=1.

SCRAT3(N3PI2)=0.

DO 1 I=2, N4

FI=1-1

TEMP=PI*PHI2N

TEMP=COS (TEMP)

SCRAT3(I)=TEMP

ISUB=N2+I

ISUB1=NP1-I

SCRAT3(ISUB1)=TEMP

1  SCRAT3(ISUB)=TEMP

5 L=1

DO 3 J=1, NSTAGE

NWI=L

L=2*L

N2J=N/2

NP=N2J

DO 2 X=1, NI

IN2J=(T-1)*N2J

IN2K=IN2J+1

IN2JI=IN2K+N4

w1=SCRAT3(IN2K)

64
GO TO ISIGN1(6,7)
6 W2=SCRAT3(IN2JI)
GO TO 8
7 W2=SCRAT3(IN2JI)
8 DO 2 IR=1,N
   ISUB=IR+IN2J
   ISUB1=ISUB+IN2J
   ISUB2=ISUB1+N2J
   ISUB3=ISUB+M2
   WR=2*XR(ISUB2)-W2*XI(ISUB2)
   WI=W2*XR(ISUB2)+W1*XI(ISUB2)
   SC1=ISUB1*XR(ISUB1)+WR
   SC2=ISUB1*XI(ISUB1)+WI
   SC3=XR(ISUB1)-WR
   SC4=XI(ISUB1)-WI
  2 CONTINUE
DO 3 IR=1,N
3 XR(IR)=SC1(IR)
   XI(IR)=SC2(IR)
   IF(SIGN)10,9,9
9 DO 4 IR=1,N
   XR(IR)=XR(IR)/FLTH
   XI(IR)=XI(IR)/FLTH
10 RETURN
END

23647 WORDS OF MEMORY USED BY THIS COMPILATION
SUBROUTINE HARMON (PS,NPEAKS,ISTART,MARGIN,SPACE,COUNT)
C THIS SUBROUTINE DETERMINES THE MOST FREQUENTLY OCCURRING
C PAIRWISE SPACING BETWEEN THE LARGEST PEAKS IN THE POWER
C SPECTRUM AND THE NUMBER OF TIMES IT OCCURRED.
DIMENSION PS(512),KCOUNT(20),ITAB(20),IFREQ(10)
DO 9 I=1,NPEAKS
   LPEAK=ISTART
   PEAK=PS(ISTART)
   JSTART=ISTART+1
   DO 1 J=JSTART,512
      IF(PEAK.GE,PS(J)) GO TO 1
      PEAK=PS(J)
1      CONTINUE
      IF(PEAK.LT,0.) GO TO 17
      IFREQ(I)=LPEAK
   PSI=LPEAK
   JSTART=LPEAK+1
2   DO 4 J=JSTART,512
      PSJ=PS(J)
      IF(PSJ.LT,0.) GO TO 5
      DIF=ABS(PS(J-1)-PSJ)
      IF(DIF.GE,0.) GO TO 4
      TEST=.5*(PEAK-ABS(PS(J-1)))
      IF(TEST.GT,PEAK) GO TO 5
      PS(4)=PSJ
      JJ=J+1
3   DO 3 JJ=JJJ,512
      PSJ=PS(JJ)
      IF(PSJ.LT,0.) GO TO 5
      DIF=ABS(PS(JJ-1)-PSJ)
      IF(DIF.GT,.5,33,33
      3 PS(JJ)=PSJ
      GO TO 5
4   PS(J)=PSJ
   GO TO 5
33  JSTART=JJ+1
   PS(J)=PSJ
   GO TO 2
5   JSTART=LPEAK-1
6   DO 8 JJ=1,JSTART
      JS=JSTART+JJ+1
      PSJ=PS(J)
      IF(PSJ.LT,0.) GO TO 9
      DIF=PSJ-ABS(PS(J+1))
      IF(DIF.LE,0.) GO TO 8
      TEST=.5*(PEAK-ABS(PS(J+1)))
      IF(TEST.GT,PEAK) GO TO 9
      PS(J)=PSJ
      JJ=J+1
7   DO 7 JJJ=1,JJJ
   7 CONTINUE
   9 CONTINUE
50  CONTINUE
J=JJJ-JJJJ+1
PS(J)=PS(J)
IF(PSJ.LT.0.) GO TO 9
DIF=PS=ABS(PS(J+1))
IF(DIF).LT.77.77.7
7 PS(J)=PSJ
GO TO 9
8 PS(J)=PSJ
GO TO 9
77 JSTART=J-1
PS(J)=PSJ
GO TO 6
9 CONTINUE
GO TO 18
17 NPEAKS=I-1
18 DO 10 I=1,512
10 PS(I)=ABS(PS(I))
CALL SETUP(1FREQ,NPEAKS)
K=0
11 KCOUNT(I)=0
M=NPEAKS+1
DO 15 I=1,N
15 JSTART=I+1
DO 15 J=JSTART,NPEAKS
IDIF=1FREQ(J)-1FREQ(I)
MIN=IDIF-MARGIN
MAX=IDIF+MARGIN
IF(K.EQ.0) GO TO 13
DO 12 K=1,K
IF(ITAB(KK).LE.MAX.AND.ITAB(KK).GE.MIN) GO TO 14
12 CONTINUE
IF(K.GE.20) GO TO 15
13 K=K+1
ITAB(K)=IDIF
KK=K
14 KCOUNT(KK)=KCOUNT(KK)+1
15 CONTINUE
IND=1
MAXIMUM=KCOUNT(1)
DO 16 I=2,K
16 IF(MAXIMUM.GE.KCOUNT(I)) GO TO 16
IND=I
MAXIMUM=KCOUNT(I)
CONTINUE
COUNT=KCOUNT(IND)
SPACE=ITAB(IND)
RETURN
END

23754 WORDS OF MEMORY USED BY THIS COMPILATION
SUBROUTINE SORTUP (IRAY,N)
C THIS SUBROUTINE IS CALLED BY HARMON TO ORDER THE
C N LARGEST PEAKS ACCORDING TO THEIR AMPLITUDES.
DIMENSION IRAY(N)
M=N-1
DO 2 I=1,M
IND=I
LITTLE=IRAY(I)
JSTART=I+1
DO 1 J=JSTART,M
IF(IRAY(J) .GE. LITTLE) GO TO 1
LITTLE=IRAY(J)
IND=J
1 CONTINUE
ITEMP=IRAY(I)
IRAY(I)=LITTLE
2 IRAY(IND)=ITEMP
RETURN
END

23709 WORDS OF MEMORY USED BY THIS COMPILATION
SUBROUTINE THRESH (PS, ISTART, LEVELS, PIST)
C THIS SUBROUTINE COMPARES THE AMPLITUDES OF
C ELEMENTS IN THE POWER SPECTRUM AGAINST A NUMBER
C OF EQUALLY SPACED THRESHOLDS AND RETURNS THE
C NUMBER OF ELEMENTS WHICH FALL BETWEEN THESE
C THRESHOLDS.

DIMENSION PS(512), PIST(LEVELS)
PEAK=PS(ISTART)
SMALL=PEAK
JSTART=ISTART+1
DO 1 J=JSTART, 512
SMALL=AMIN1(SMALL, PS(J))
1 PEAK=AMAX1(PEAK, PS(J))
DIVIDE=(PEAK-SMALL)/FLOAT(LEVELS)
DO 3 J=1, LEVELS
3 PIST(J)=0
DO 4 I=ISTART, 512
IND=(PS(I)-SMALL)/DIVIDE+1.
4 IF(IND.GT.LEVELS) IND=LEVELS
PIST(IND)=PIST(IND)+1.
RETURN
END

23780 WORDS OF MEMORY USED BY THIS COMPILATION.
SUBROUTINE SQAR(X, SCRT, R)
C     THIS SUBROUTINE CALCULATES R, WHERE R IS DEFINED
C     AS THE RATIO OF THE MAXIMUM DEVIATION FROM THE
C     MEAN TO THE AVERAGE DEVIATION FROM THE MEAN IN A
C     GIVEN 1/2 SECOND WINDOW OF THE TIME WAVEFORM,
C     DIMENSION X(512), SCRT(512)

SUM=0,
10 SUM=SUM+X(I)
   SUM=SUM/512,
   DO 20 I=1,512
20 SCRT(I)=ABS(X(I)-SUM)

XMAS=0,
   SUM=0,
   DO 40 L=1,512
   XMAS=MAX1(XMAS, SCRT(L))
40 SUM=SUM+SCRT(L)
R=(512.*XMAS)/SUM
RETURN
END

23648 WORDS OF MEMORY USED BY THIS COMPILATION
SUBROUTINE BINRAT(PS, ISTART, FEAT1, FEAT2)

C THIS SUBROUTINE CALCULATES THE RATIOS OF ENERGY
C BETWEEN ONE AND TWENTY HERTZ AND BETWEEN FORTY-ONE
C AND SIXTY HERTZ TO THE ENERGY BETWEEN TWENTY-ONE
C AND FORTY HERTZ.

DIMENSION PS(512)

SUM1=0,
SUM2=0,
SUM3=0,
ISTOP=ISTART+19
DO 1 I=ISTART, ISTOP
SUM1=SUM1+PS(I)
1 SUM2=SUM2+PS(I+20)
SUM3=SUM3+PS(I+40)
FEAT1=SUM1/SUM2
FEAT2=SUM3/SUM2
RETURN
END

43648 WORDS OF MEMORY USED BY THIS COMPILATION
SUBROUTINE SPFCVRFPS7NVTTFRR7WC CREATEBT
C     THIS SUBROUTINE CALCULATES THE RATIO OF ENERGY
C     ABOVE A SPECIFIED FREQUENCY TO THE ENERGY BELOW
C     AND ALSO CREATES A VECTOR WHOSE COMPONENTS
C     CONTAIN NORMALIZED ENERGY VALUES FROM CONSECUTIVE
C     FREQUENCY BINS OF THE POWER SPECTRUM,
C
DIMENSION PS(512),VEXT(NVECT)
DO 1 I=1,NVECT
  VECT(I)=0,
  SUM=0,
  DO 5 I=1,NVECT
    J=5*I-3
    K=5*I+1
    DO 2 L=J,K
      VECT(I)=VECT(I)*PS(L)
      2      SUM=SUM*VECT(I)
    DO 6 I=1,NVECT
      VECT(I)=VECT(I)/SUM
 1    CONTINUE
  2    RGYAT=0
  3    DO 4 I=1,NVECT
      RGYBT=RGYBT+PS(I)
      J=ITH+1
      DO 4 I=J,512
        RGYAT=RGYAT+PS(I)
        4    RETURN
  6    RGYAT=RGYAT/RGYBT
  5    RETURN
END

23715 WORDS OF MEMORY USED BY THIS COMPILATION
SUBROUTINE PEPKI(PS, ISTART, THRESH, COUNT)

C THIS SUBROUTINE CALCULATES THE NUMBER OF PEAKS
C IN A POWER SPECTRUM WHICH ARE ABOVE SOME SPECIFIED
C PERCENTAGE OF THE MAXIMUM PEAK.
DIMENSION PS(512)

XMIN=PS(ISTART)

XMAS=XMIN
INIT=ISTART+1
DO 1 I=INIT,512
XMIN=AMIN1(XMIN,PS(I))
1 XMAS=AMAX1(XMAS,PS(I))
TEST=(XMAS-XMIN)*THRESH

COUNT=0,
PSMIN=PS(I)-XMIN
IF(PSMIN,GT,TEST) GO TO 2
ISWIT=0
GO TO 3
2 ISWIT=1
DO 5 I=2,512
PSMIN=PS(I)-XMIN
IF(ISWIT,EQ,1) GO TO 4
IF(PSMIN,GT,TEST) ISWIT=1
GO TO 5
4 IF(PSMIN,GT,TEST) GO TO 5
ISWIT=0
COUNT=COUNT+1,
5 CONTINUE
RETURN
END

23778 WORDS OF MEMORY USED BY THIS COMPILATION
MOE

MOE

MOE

MOE

MOE

MOE
<table>
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<th>LBL</th>
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<td>RD9 SAVE 0, 1, 2, 3, 4, 5</td>
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| 000001 | 0000002220003 | 000 |
| 000002 | 000000221003 | 000 |
| 000003 | 000000222003 | 000 |
| 000004 | 000000223003 | 000 |
| 000005 | 000000224003 | 000 |
| 000006 | 000000225003 | 000 |
| 000007 | 003045600000 | 010 |
| 000010 | 003045740000 | 010 |
| 000011 | 003045741000 | 010 |
| 000012 | 000000740000 | 010 |
| 000013 | 000000741000 | 010 |
| 000014 | 000007740000 | 010 |
| 000015 | 000000741000 | 010 |
| 000016 | 000000742000 | 010 |
| 000017 | 000000745000 | 010 |
| 000020 | 000002235011 | 000 | 6 | LDA 2, 1 |
| 000021 | 003044755000 | 010 | 7 | STA BUF |
| END OF BINARY CARD READ9TRK |
| 000023 | 0000002235031 | 000 | 9 | LDA 6, 1* |
| 000024 | 003045755000 | 010 | 10 | STA FC |
| 000026 | 003045755000 | 010 | 11 | LDX = 0, DU |
| 000027 | 0000002235031 | 000 | 12 | LDA DUMMY |
| 000030 | 00304075031 | 010 | 13 | STA TALLY |
| 000031 | 00304075031 | 010 | 14 | LDA DUMMYB |
| 000032 | 0000002235031 | 000 | 15 | STA TALLYB |
| 000033 | 0000002235031 | 000 | 16 | MIE GYTNOS |
| 000034 | 0000002235031 | 000 | 17 | RT2 |
| 000035 | 0000002235031 | 000 | 18 | ZERO FC, DCW |
| 000036 | 00304375031 | 010 | 19 | ZERO STR |
| 000037 | 00304375031 | 010 | 20 | MIE GEROND |
| 000038 | 00304375031 | 010 | 21 | LDA STR |
| 000040 | 00304375031 | 010 | 22 | ALS 2 |
| 000041 | 00304375031 | 010 | 23 | AWA = 777400, DU |
| 000042 | 00304375031 | 010 | 24 | CMFA = 211400, DU 9 TRACK EOF |
| 000043 | 00304375031 | 010 | 25 | ZNZ LOOP |
| 000044 | 00304375031 | 010 | 26 | LDA = 1, DL |
| 000045 | 00304375031 | 010 | 27 | STA 7, 1* |
| END OF BINARY CARD READ9TRK |
| 000046 | 00304375031 | 010 | 28 | LDA EXIT |
| 000047 | 00304375031 | 010 | 29 | LOOP LDQ = 1472 |
| 000050 | 00304375031 | 010 | 30 | QLS 5 |
| 000051 | 00304375031 | 010 | 31 | STCO TALLY, 06 |
| 000052 | 00304375031 | 010 | 32 | LDQ = 1472 |
| 000053 | 00304375031 | 010 | 33 | QLS 6 |
| 000054 | 00304375031 | 010 | 34 | STCO TALLY9, 06 |
20915 02  04-03-73  17,648

000140   85 IA  BSS  1472
003040  000140  270C  40  010
END OF BINARY CARD READ9TRK
003041  000140  270C  00  010
003042   86 DUMMY TALLY IA,1472,0
003043  87 DUMMY TALLY IA,1472,0
003044     88 LOCO BSS  1
003045     89 FC  BSS  1
003046  90 BUF BSS  1

ERROR LINKAGE

LITERALS

003050  00000000270C  000
003051  000000000001  000
003052  000000000155  000
003053  000000000000  000
END OF BINARY CARD READ9TRK

3054 IS THE NEXT AVAILABLE LOCATION.

GMAP VERSION/ASSEMBLY DATES JMPA 110171/102971  JMPB 110171/102971

THERE WERE NO WARNING FLAGS IN THE ABOVE ASSEMBLY.

77
C      SEISMIC SENSOR FEATURE TAPE GENERATOR
C      THIS IS THE CDC 1604 PROGRAM WHICH CONVERTS DATA CARDS TO
C      AN OLPARS COMPATIBLE MAGNETIC TAPE.
C
PROGRAM ALSO DATA
DIMENSION X(I30),IX(130),NUM(20),INAME(20),LFOR(20),IHEAD(7)
EQUIVALENCE(X,IX)
READ 1007,19K1P
1 07 FORMAT(15)
READ 1000+LFOR
READ 1000+INAME
1 00 FORMAT(10A8)
READ 1001+NDIM,ITOT,NUM
NP3=NDIM=3 & VLC=NDIM=1
1 01 FORMAT(25I3)
DO 7 I=1,15K1P
7 READ TAPE 10
DO 1 IDUM=1,ITOT
ITOT=NUM(IDUM)
DO 2 I=1,ITOT
READ 1006+IHEAD
1 06 FORMAT(2X,12,2X,15,2X,0.2,2X,4(15,2X))
READ LFOR,(X(J),J=1,NDIM)
1 02 FORMAT(5(1X,F3.0))
IX(NDIM+1)=IHEAD(1)+10000+IHEAD(3)+1000+IHEAD(7)+1000+IHEAD(5)
IX(NDIM+2)=INAME(IDUM),ANN,778
IX(NDIM+3)=INAME(IDUM)
WRITE TAPE 10,(X(JJ),JJ=1,NP3)
2 CONTINUE
1 CONTINUE
PAUSE
END FILE 10
PRINT 1005
1 05 FORMAT(1M1)
6 READ TAPE 10,(X(KK),KK=1,NP3)
IF(EOF,10)4,5
5 PRINT 1003,(X(KK),KK=1,NDIM)
1 03 FORMAT(1X=10E11,3)
PRINT 1004,(X(KK),KK=NLD,NP3)
1 04 FORMAT(1X=110.2(1X,A8),//)
GO TO 6
4 REWIND 10
END
APPENDIX B

PROBABILITY OF CONFUSION MEASURES
**PAIR C/H RANKINGS**

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**PAIR C/A RANKINGS**

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80
### Pair M/A Rankings

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APPENDIX C

LINEAR DISCRIMINANTS
**FISHER LOGIC**

**NODES IN SET**

WEI M  APC A  BIG T  MEN M  131 C

**PAIR 1**  + NODE APC A  - NODE WEI M  FISHER

COEFFICIENTS


THRESHOLDS

PAIR 2  + NODE BIG T  - NODE WEI M  FISHER

COEFFICIENTS


THRESHOLDS

PAIR 3  + NODE BIG T  - NODE APC A  FISHER

COEFFICIENTS


THRESHOLDS

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