ORINCON CORPORATION

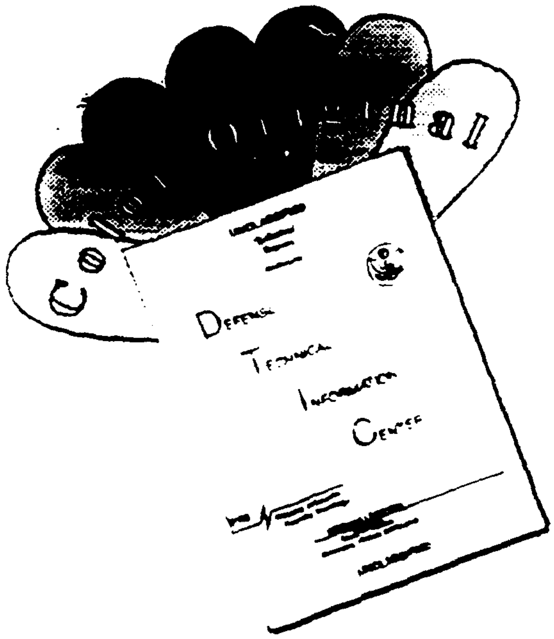
OCR 92-U-0284

CONDITIONED BASED MACHINERY MAINTENANCE (HELICOPTER FAULT DETECTION)

Progress Report for the Period Covering
1 May Through 30 June 1992

30 June 1992

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF COLOR PAGES WHICH DO NOT REPRODUCE LEGIBLY ON BLACK AND WHITE MICROFICHE.

ORINCON CORPORATION

OCR 92-U-0284

CONDITIONED BASED MACHINERY MAINTENANCE (HELICOPTER FAULT DETECTION)

Progress Report for the Period Covering
1 May Through 30 June 1992

30 June 1992

Contract No. N00014-92-C-0059
CDRL No. 0001AA

Submitted to:
Scientific Officer
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000
Attn: Dr. Thomas McKenna

Distribution:

Scientific Officer	Code N00014	1/0
Administrative Contracting Officer	Code S0514A	1/0
Director, NRL	Code N00173	1/0
DTIC	Code S47031	2/0

9363 Towne Centre Drive, San Diego, CA 92121 Phone: (619) 455-5530 FAX #: (619) 453-9274

I. PROGRESS MADE DURING PERIOD, PROBLEMS, AND RECOMMENDATIONS

Progress

Significant progress was made on the Phase I Conditioned Based Machinery Maintenance SBIR in the first two months of the project. All of the signal processing algorithms to be used for the project have been developed, coded onto the ORINCON in-house computer system, and used to process an initial data set (the Hollins data). Figure 1 shows the processing scheme that was used for the Hollins data set system. Initially, four feature extractors were considered. They are standard FFT processing, instantaneous time-frequency representation (the AOK GTFR), Prony's model method, and a wavelet transform found using the Gabor wavelet. As indicated in Figure 1, a hierarchical neural net scheme is being used to process the data[1]. All of the feature extractors' outputs are initially processed by a first layer of neural nets. The first layer of neural nets operates on only single-feature data. The output from the first layer of nets is then input to a second layer net for fusion processing.

A first pass of processing the Hollins data set was made. For the results described here, no investigation of the parameters used for feature extraction was made, nor were the architectures for the single-feature networks adjusted. The only parameter adjusted was the time duration of the input retina to the fusion network of the hierarchical network.

Each of the neural networks used is a three-layer perceptron. Training is performed until the RMS training error from each of the networks is approximately 0.01. In past work at ORINCON, this RMS error has resulted in networks that give robust detection/classification performance for both training and test data sets. Visual inspection of the single-feature network outputs on test data resulted in the AOK GTFR and Prony model spectra being dropped from the fusion network processing (i.e., the dotted lines in Figure 1 show connections that were initially considered but are not included in the final system described here). It is important to note that these results only apply to the Hollins data set and may not hold for additional data sets.

Figures 2 through 7 show specific results for each of the class categories included in the Hollins data set. There are five separate windows in the display shown in each of the Figures. The windows labeled 'fft,' 'prony,' 'AOK,' and 'WAVELET' correspond to individual feature extractors as well as the output activations from the single feature networks. The network activations correspond to:

Column 6 = Normal gearbox,

Column 1 = Bearing inner race fault,

Column 2 = Bearing rolling element fault,

Column 3 = Bearing outer race fault,

Column 4 = Gear spall fault, and

Column 5 = Gear 1/2 tooth cut fault.

The neural net outputs are temperature encoded. Dark blue or black indicates a relatively low activation level. Yellow or white indicates a relatively high activation level. The feature extractors show the same amount (or time duration) of data; however each extractor uses different processing parameters so that the output scan rates are different. For example, for the 'prony' and

[1]T.Brotherton, D.Fogel, and E.Mears, Final report for applications of data fusion to signal processing Phase I SBIR, sponsored by DARPA, ARPA order no. 5916, contract no. DAAH01-91-C-R304.

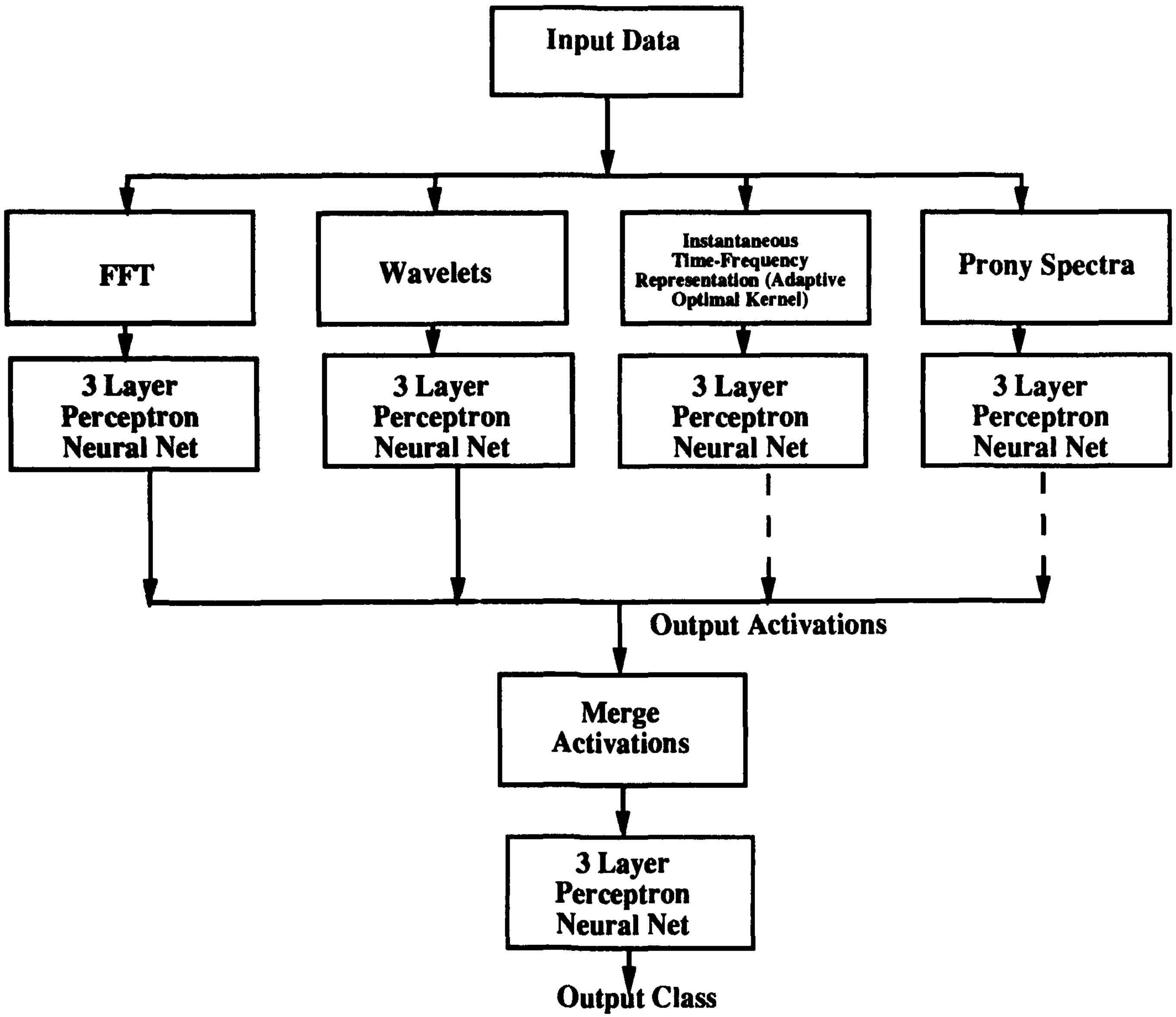


Figure 1. Hollins Data Set Processing

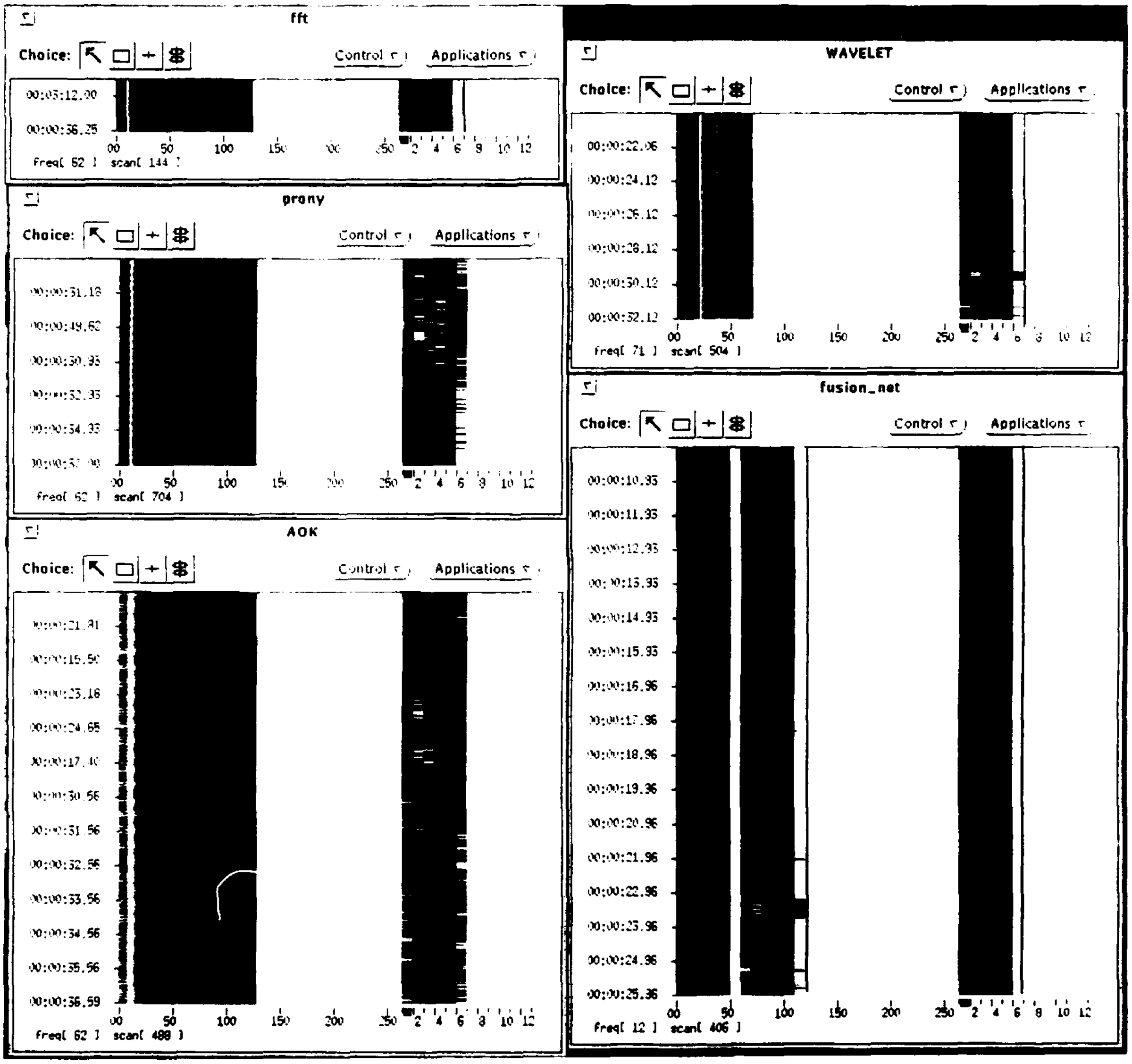


Figure 2. Hollins Data: Normal Data (No Faults)

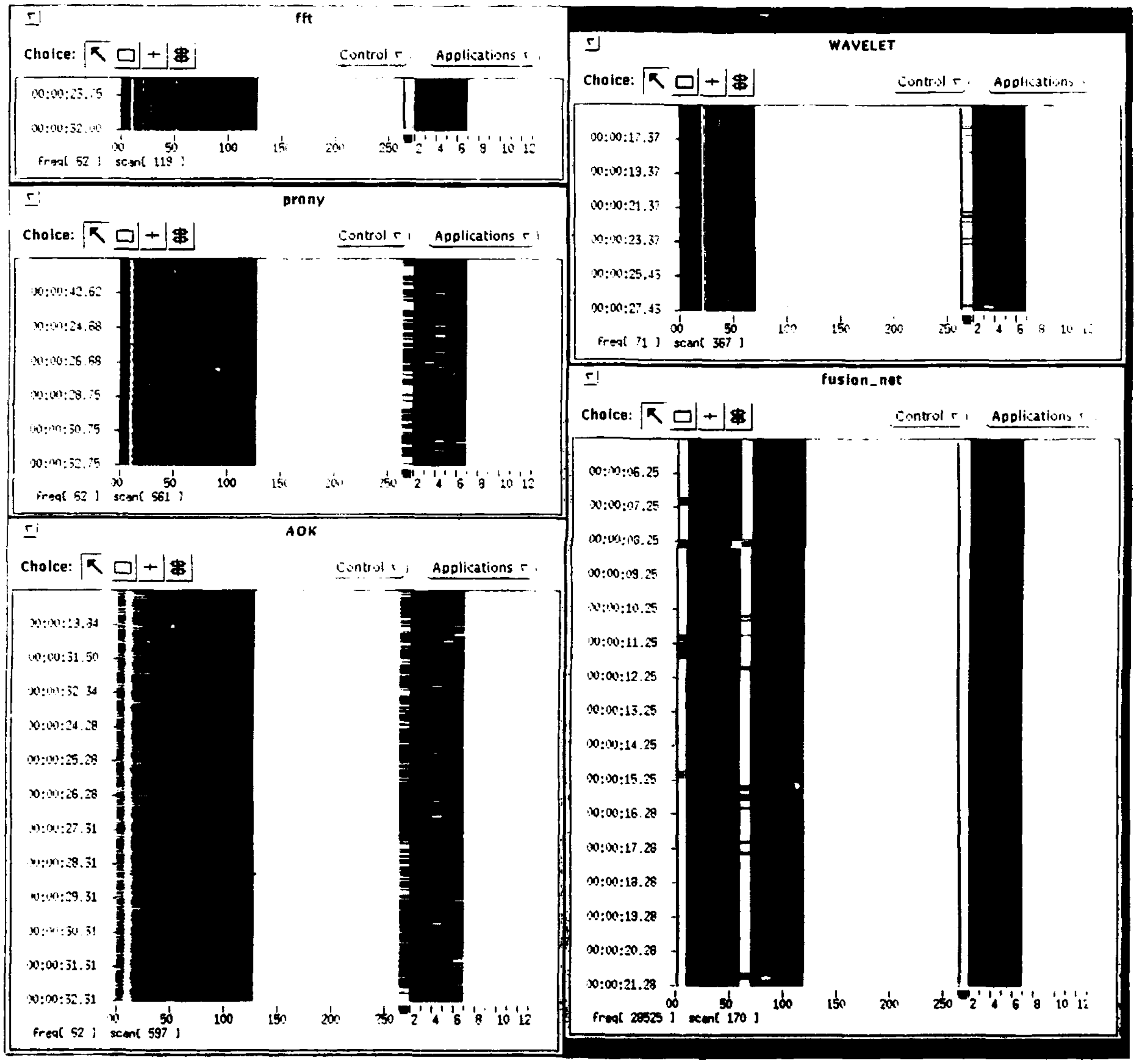


Figure 3. Hollins Data: Bearing, Inner Race Fault

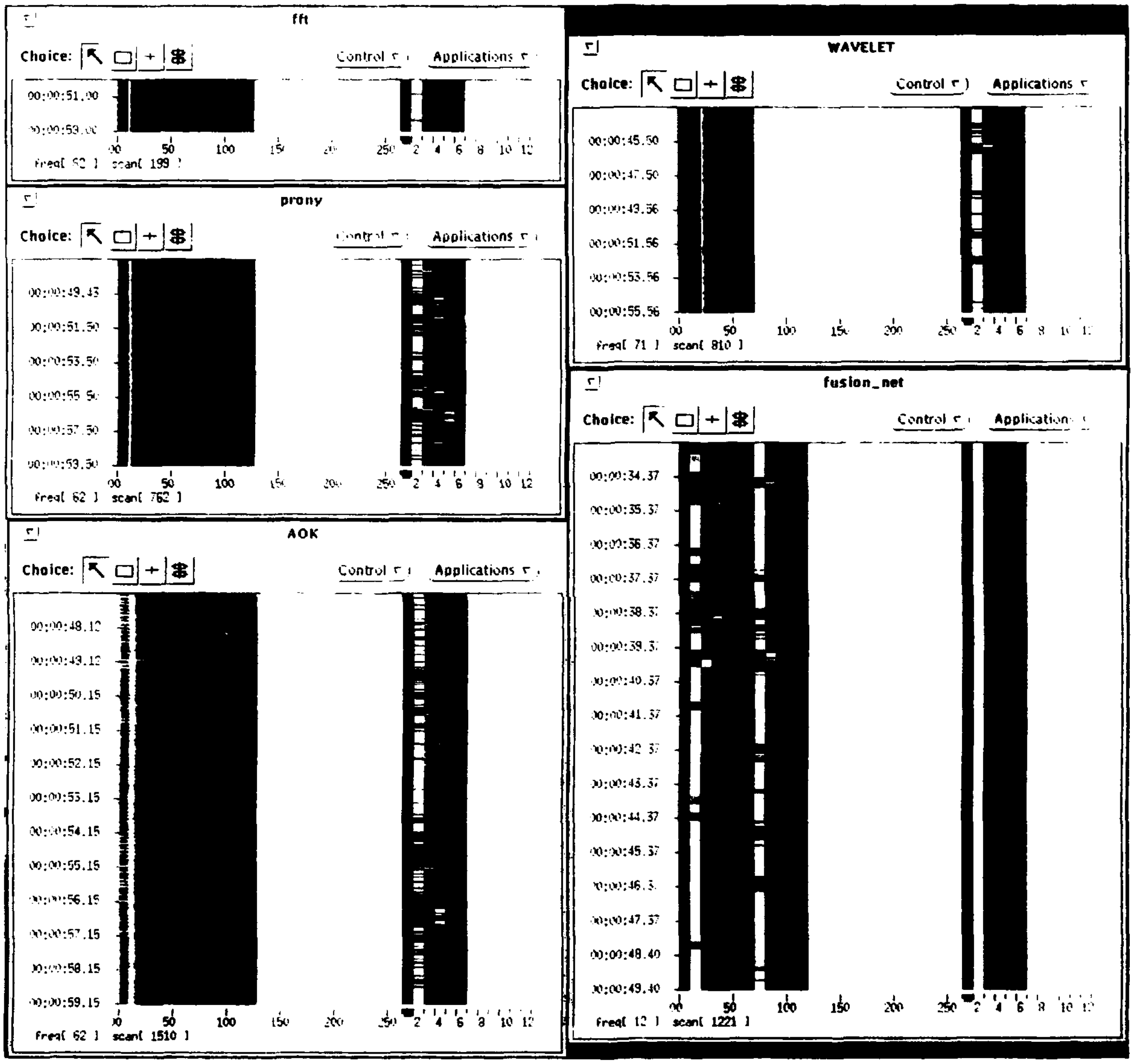


Figure 4. Hollins Data: Bearing, Rolling Element Fault

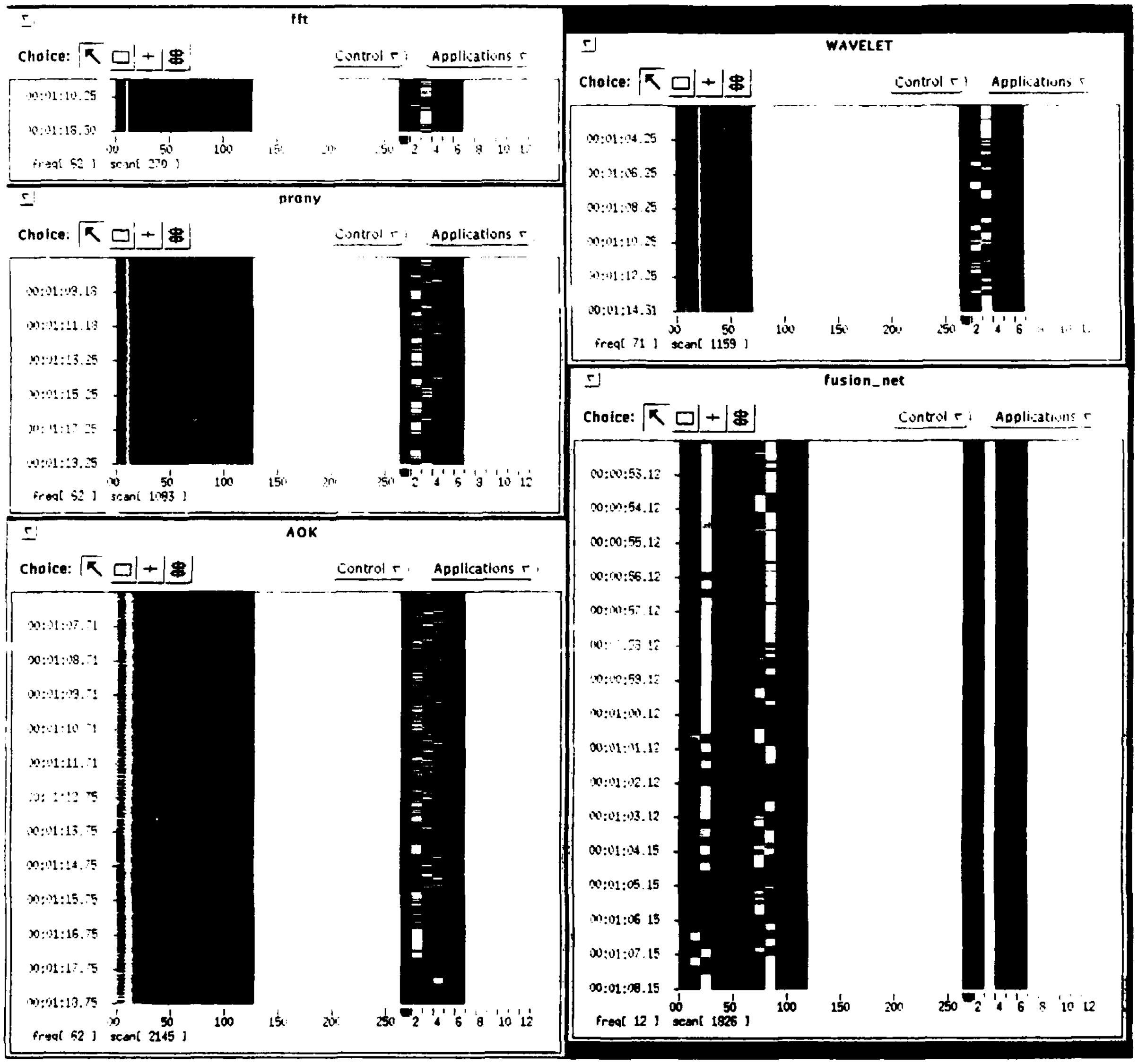


Figure 5. Hollins Data: Bearing, Outer Race Fault

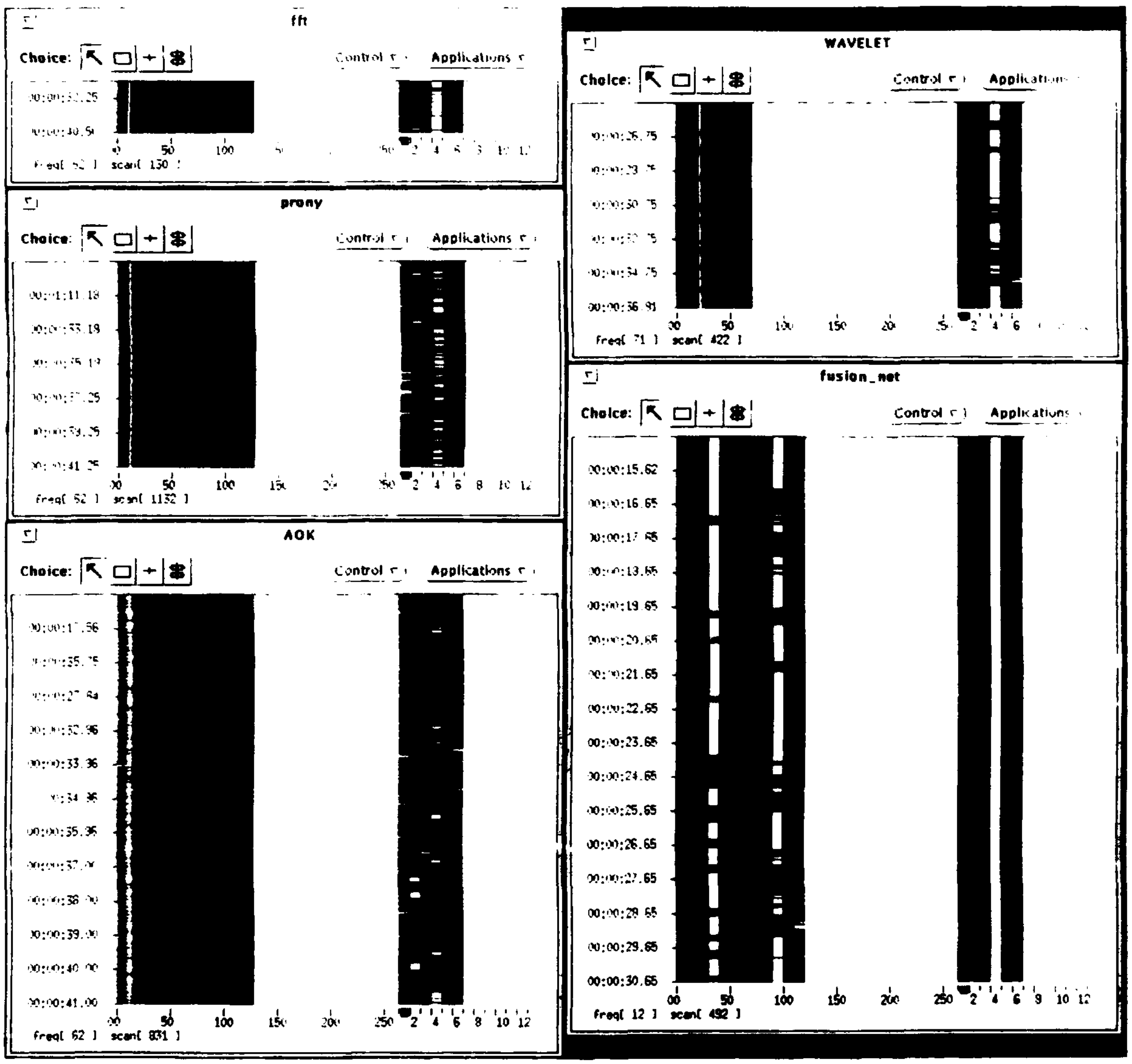


Figure 6. Hollins Data: Gear, Spall Fault

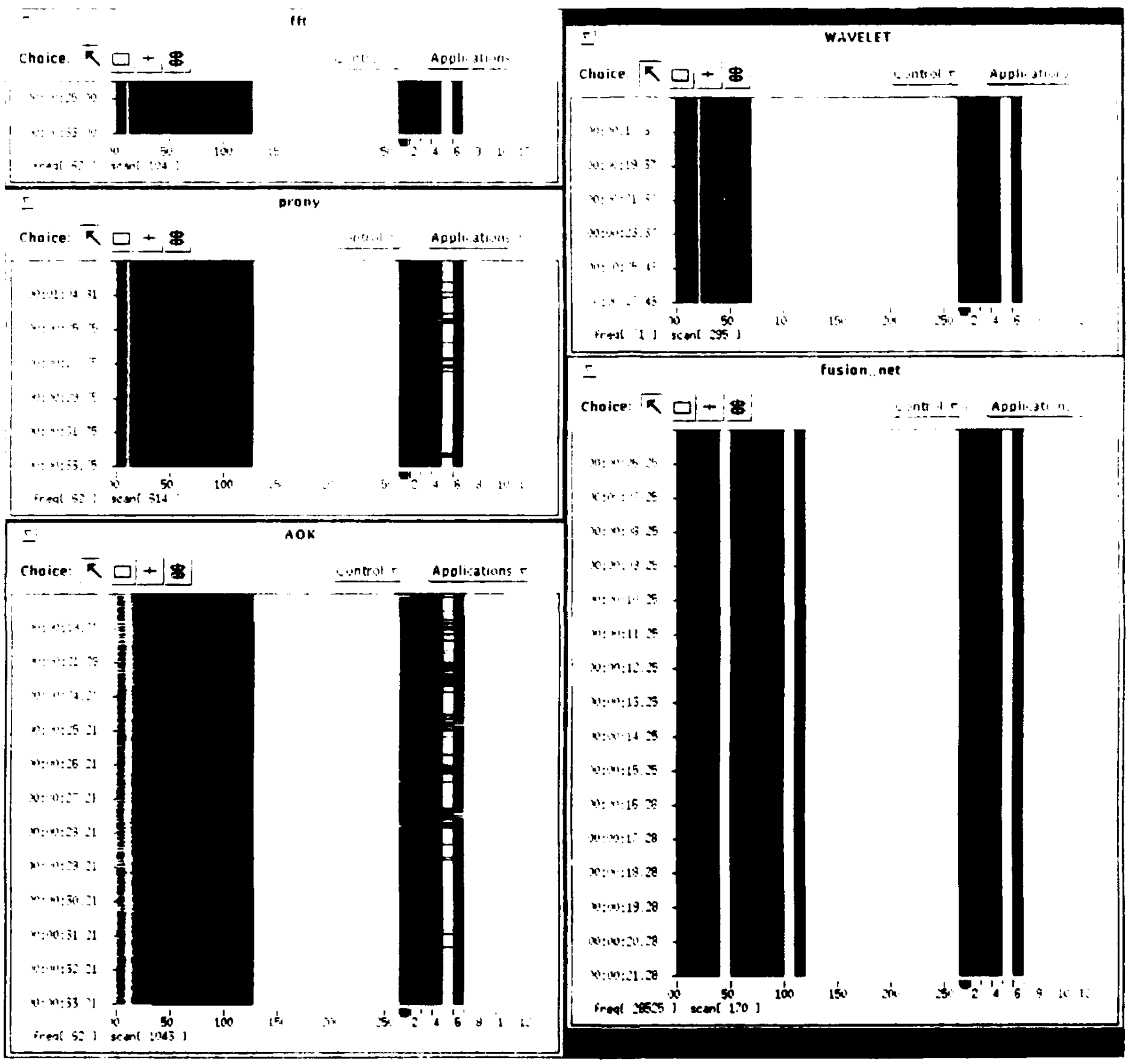


Figure 7. Hollins Data: Gear, 1/2 Tooth Cut Fault

'WAVELET' feature extractors there are four output scans for each output scan of the 'fft' extractor. The 'AOK' extractor outputs eight scans for each of the 'fft' extractors.

The window labeled 'fusion_net' shows the inputs and the output for the second-layer net in the hierarchical neural net. The input features are the outputs from the FFT and Wavelet first-layer networks as shown in Figure 1. The FFT outputs from the first layer have been stretched in time to synchronize with the faster-running Wavelet feature extractor. The figures show results for processing of test data that contains only the event of interest.

Each of the extractors gives a different spectral representation of the data. The ideal neural net performance would result in the column corresponding to the gearbox condition being bright white when data for that condition is input to the system and black for the other fault conditions. For example, in Figure 2 (normal gearbox), the sixth column should be bright white while all the other columns are dark. As seen, for the fft net and the fusion net outputs, this is true. Dropouts in the normal gearbox column or activations in other columns correspond to false alarms within the system. Low or no activations for the event of interest column, when the event is present, correspond to missed detections or misclassifications. As seen in the figure, the wavelet net gives some false alarms, while the AOK GTFR and Prony nets give very marginal performance.

For all cases the fusion_net output activations are ideal. Figure 4 is perhaps the most interesting. Here, we see that both the FFT and Wavelet nets give marginal performance. However, the fusion net output is still outstanding; the third column is bright white for the duration shown, while all the other columns are quite dark. The fusion net uses a fairly long integration time (200 scans, which is about half the length of the display shown in the fusion net). Long integration times (i.e., retinas with long time extents) are possible with the second net in the hierarchical network. This is because there are relatively few inputs to the network (here there are only 12 inputs to the second-layer network). The first-layer nets are restricted to have short time extents (unless averaging of time scans is performed). This is because a scan is made up of typically 128 or 256 points so that large numbers of scans are not computationally tractable. The long integration times in the second-layer net allow the net to 'learn' that the inputs from the first-layer nets are dropouts and false alarms and can be ignored.

The results shown are qualitative. Currently tools for developing quantitative performance results are being developed. We are awaiting the more complicated data set that is to be supplied by the government for processing. Specific progress relative to the SOW follows:

1. Identify Features and Parameters to Use

All feature extractors proposed have been developed and coded onto the ORINCON computer system. Parameters for processing will be identified when the data of interest is received.

2. Develop Feature Set Processing

Completed. Additional features will be included as they are developed on other ORINCON projects.

3. Identify Data Sets/Segments from Westland Helicopters

This task has been replaced. The government will supply the data. ORINCON will process an additional fault data set.

4. Transfer and Format Data for In-House Use

Completed for the Hollins data set.

5. Process Real Data Through the Feature Extractors and Assess Utility

In progress for the Hollins data set. Preliminary results (as shown above) indicate that the FFT and Wavelet feature extractors only are required for that data set when used with the hierarchical neural net.

6. Develop Training Data Set

Completed for the Hollins data.

7. Train Neural Net

Completed for the Hollins data set with the set of feature extractor parameters used.

8. Develop Test Data Set

Completed for the Hollins data.

9. Test the System

In progress for the Hollins data. Development of specific performance measures is in progress.

10. Demonstrate the Prototype System

Not started yet.

11. Assess System Performance and Produce a Final Report

Not started yet.

12. Process an Additional Fault Detection Data Set

Not started yet. Awaiting the additional data set.

Problems

We are currently waiting for the government data that is of interest. We have also done most of the development using a system developed for an IR&D project based on the ORINCON PRISM system. The system allows for very fast training and prototype system development in trying out different signal processing parameters and feature extractors. Unfortunately, the system is incompatible with the KHOROS software recommended by the government. The outputs from the system can be made compatible with KHOROS for playback. However some time would be required to change the software modules to the KHOROS format.

Recommendations

None.

II. RESULTS RELATED TO PREVIOUSLY IDENTIFIED PROBLEM AREAS

None.

III. DELIVERABLES COMPLETED AND DELIVERED

Completed CDRLs	Date Delivered
1. 0001AA Progress Report	June 30 1992 (this deliverable)

IV. SUBCONTRACTING AND RESULTS DURING REPORTING PERIOD

None to report at this time.

V. EXTENT OF TRAVEL

Not applicable.