Applications

Advanced Acoustic Emission Data Analysis Pattern Recognition & Neural Networks Software

Envirocoustics Non Destructive Testing

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PHYSICAL ACOUSTICS CORPORATION
A MISTRAS Holdings Company

FRP Blade Data Analysis

Mortar Specimen Compression Tests

Aerial Manlift Device Testing

Metal Pressure Vessel Data Analysis

Laser Doppler Anemometry Data

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FRP Blade Data Analysis

EXPERIMENTAL SET-UP

Wind Turbine FRP Blades were Tested under Fatigue Loading and Monitored with Acoustic Emission.

Target was to investigate the possibility of distinguishing Critical Types of AE signals that indicate damage and possible failure.

TWO TYPES OF TESTS MONITORED WITH AE:

•The first loading ever applied to the blade (static, uniaxial, flapwise)

•Biaxial fatigue loading (23 cycles at 0.1 Hz), after the blade had undertaken several millions of cycles

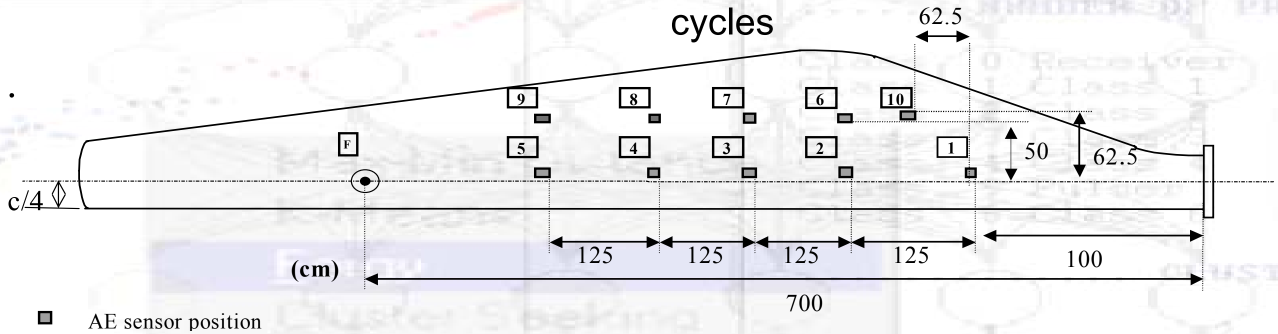

Figure 1: AE sensor position and channel numbers. Load application point.

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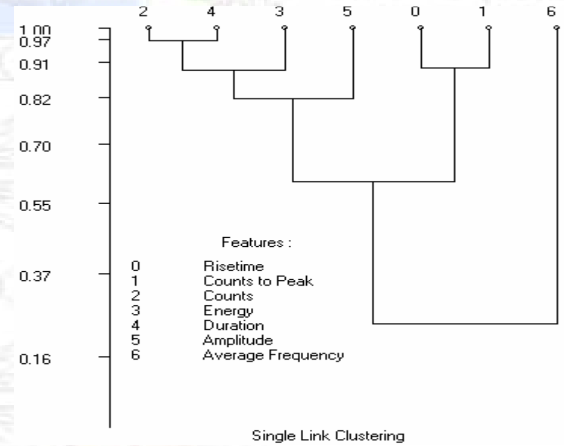
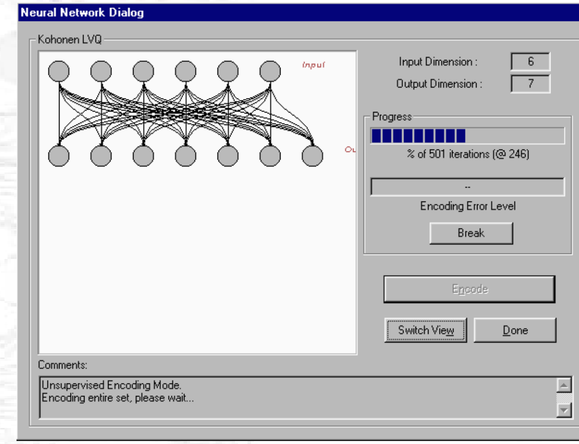
FRP Blade Data Analysis

UPR PROCEDURE

- First-hit analysis for better representation of source characteristics
- AE Feature selection, assisted by Feature Correlation Hierarchy. Selected features: Rise Time, Counts to Peak, Energy, Duration, Amplitude, Average Frequency
- AE feature-vector non-dimensionalization: 0 to 1 range
- Clustering with selected algorithms:
  - •K-Means → Minimization of Square Error
  - •LVQ Neural Net → Variation of Kohonen Neural Net
- Cluster validity assessment and optimization based on minimization of D&B R_{ij} criterion. Optimum number of resulting classes: Seven (7)





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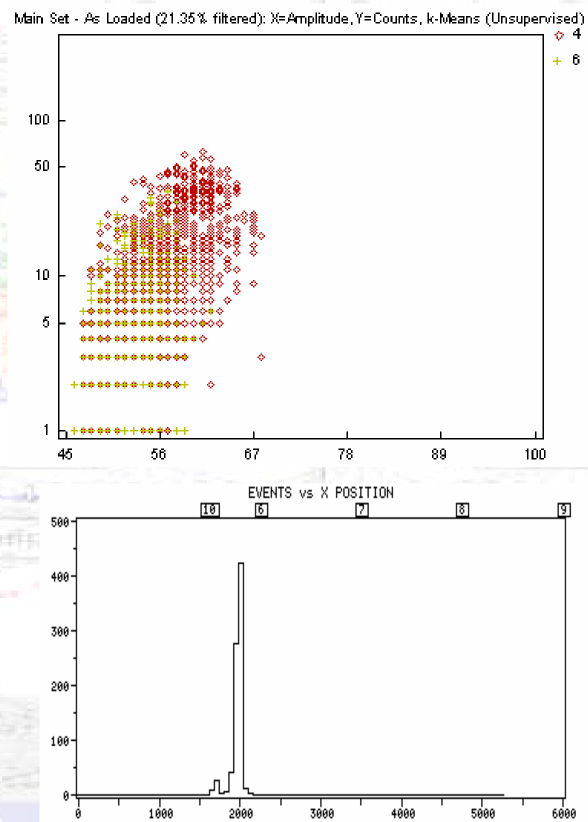
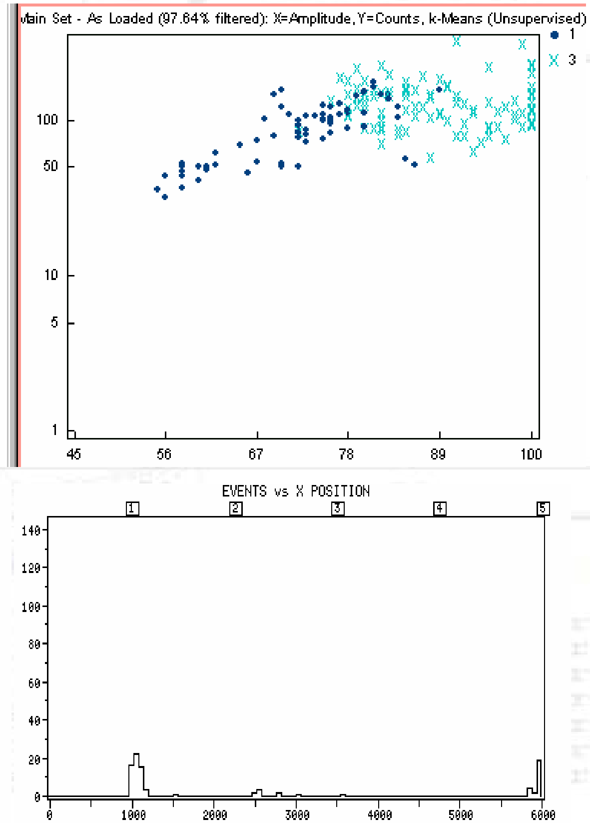
FRP Blade Data Analysis

RESULTS OF UPR ON THE FIRST STATIC TEST DATA - LOCATION

- Using PAC S/W, zonal information (rest of hits for each event) was extracted for each first-hit.
- Linear location was applied separately for classes 4 and 6 and for classes 1 and 3
- Source of classes 4 and 6 was confirmed later as a visible crack between sensors 6 and 10 at trailing edge
- Location of classes 1 and 3 coincides with internal spar end



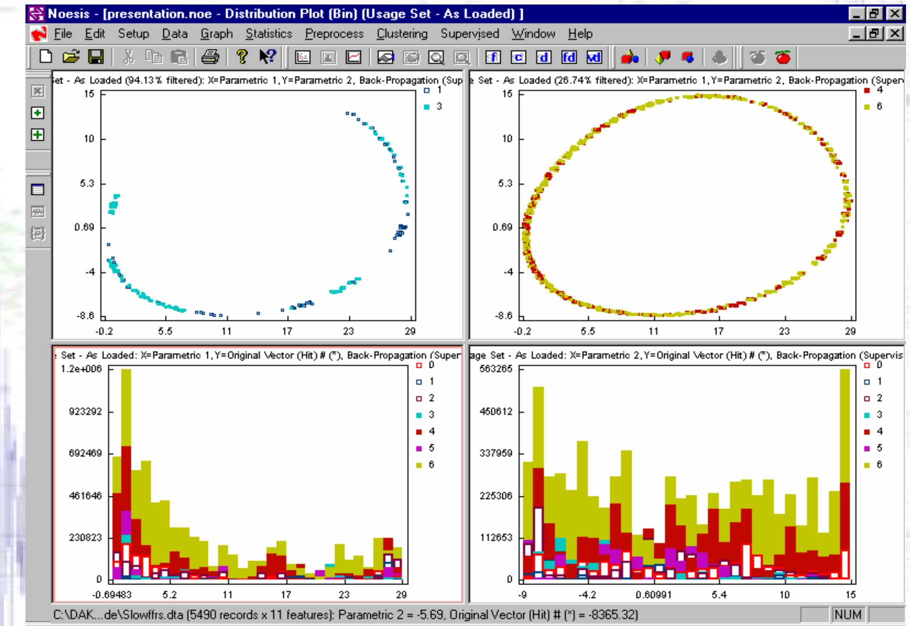
Signature and Location of Classes 4 and 6



Signature and Location of Classes 1 and 3

FRP Blade Results

RESULTS OF SPR ON THE FATIGUE TEST DATA



1) Flapwise vs. Edgewise load (Classes 1, 3)
2) Flapwise vs. Edgewise load (Classes 4, 6)
3) Distribution of Hits vs. Flapwise load, per Class
4) Distribution of Hits vs. Edgewise load, per Class

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CONCLUSIONS

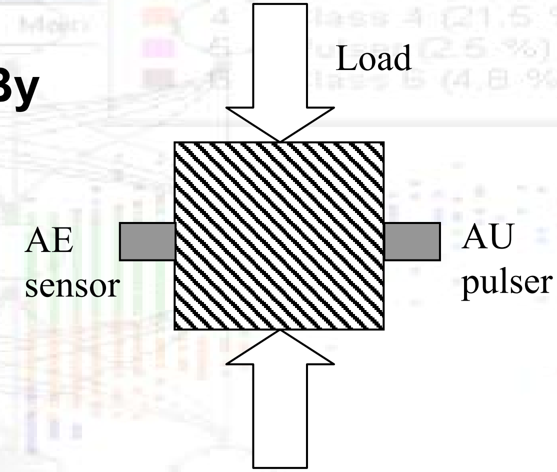
- UPR methodology applied on AE data obtained during the very first static test, yielded 7 classes of data
- **Classes varied both in terms of AE features and criticality**
- Application of **linear location on selected classes revealed that different classes were located at different parts** of the blade
- The classes which demonstrated criticality were located at the maximum chord area, where a visible crack developed after thousands of fatigue cycles, long **after** the static test
- **SPR applied on AE data from subsequent fatigue testing different classes appear at different parts of the loading cycle**

For details refer to :

Analysis of Acoustic Emission Data from Wind Turbine Blade Testing Using Unsupervised Pattern Recognition
15th International Acoustic Emission Symposium, Tokyo, Japan, 11-14 Sept. 2000
A. A., Anastassopoulos, S. J., Vahaviolos, D. A. Kouroussis, P. Vionis, J. C. Lenain, A. Proust

Mortar Specimen Compression Tests

Cubic Mortar Specimens were Tested under Compressive Loading to Failure and Monitored By Acoustic Emission and Acousto-Ultrasonic.



Target was to correlate AE and AU with failure mechanisms and microscopy findings.

METHODOLOGY, WORK SEQUENCE :

- Application of optical microscopy techniques to identify initial properties and attempt to subsequently correlate these with AE and AU measurements.
- Compression test monitored by AE and AU aiming to collect Real-Time data (features-waveforms) and to identify classes of AE signals that relate to damage and microscopy findings and investigate AU measurements when the identified classes appear.
- Aging factor is important so compression tests were performed on identical specimens at 2, 7, 28, 90 days from construction.

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Mortar Specimen Compression Tests

ACOUSTIC EMISSION SIGNATURE :

• Difficult to distinguish signatures for composition and age.

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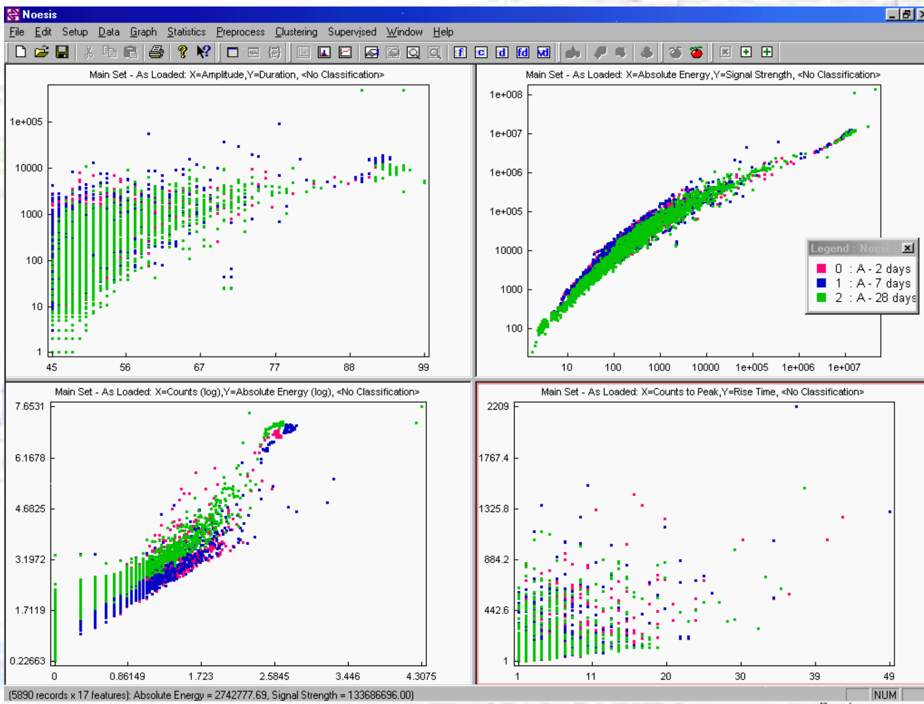
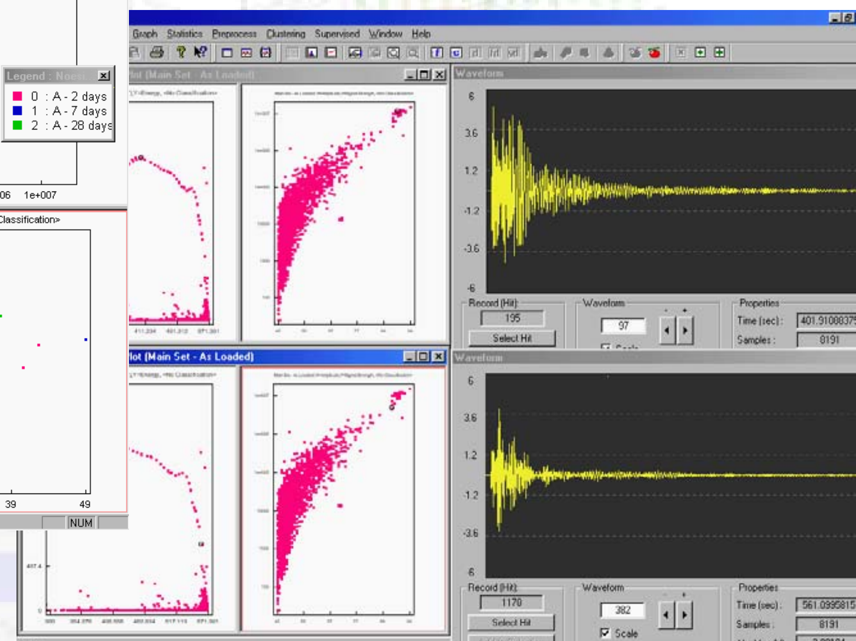


Specimen Type A, at 2, 7 and 28 days



Typical waveforms for received AU signal.

Mortar Specimen Compression Tests

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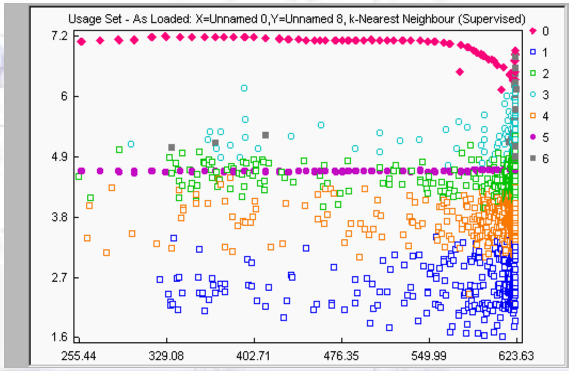
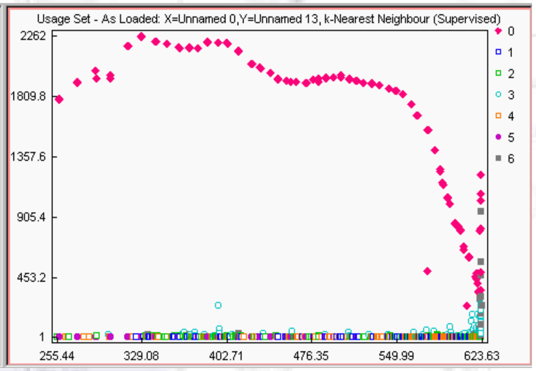
ACOUSTIC EMISSION / PATTERN RECOGNITION

- To distinguish AE, AU and pulser signals.
- To distinguish AE signal groups and attempt to correlate concrete, microscopy and AU.
- Data Pre-processing :
  - Axes normalisation via non-linear space transformation with logarithmic functions
  - Reduced feature set and feature normalisation.
- Max-Min Distance classifier for unsupervised PR revealed 7 classes (figure)
- k-NNC classifier training and application to data from the other specimens.



Log Signal Strength vs Time



Energy vs Time

Class 5 (purple) pulser signals and class 0 (red) received pulser signals successfully recognised.

Mortar Specimen Compression Tests

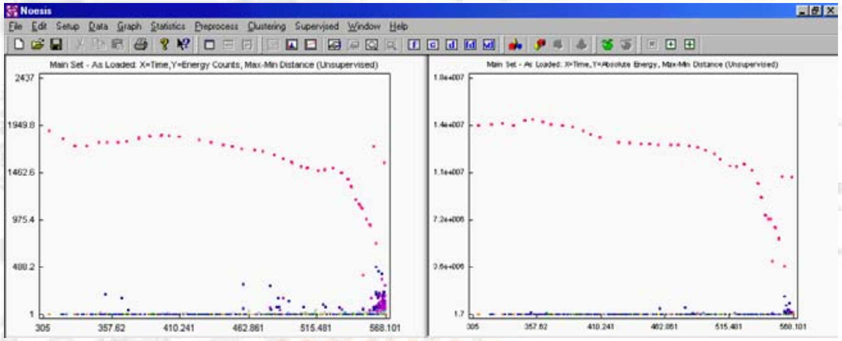
ACOUSTO-ULTRASONICS :

• Early indications of on-coming failure (approx. 85% max load) from most signal features (see figure).

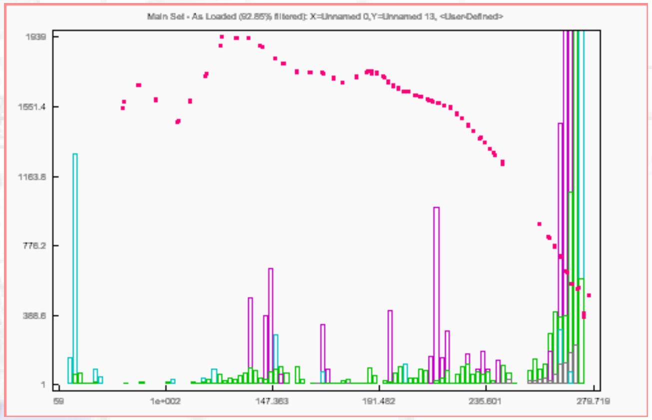
• Significant variations for most features throughout loading indicating changes in the specimen.

• AE signal classes correlating with AU appear to be 2, 3 and 6.

• AU measurements varied distinctly with age and composition.



Variations of signal features for specimens A - 28 days.



AU dependency on emission in classes 2 (low energy, green) and 3 (higher energy, purple) for specimen A-7days.

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Mortar Specimen Compression Tests

ACOUSTIC EMISSION / PATTERN RECOGNITION :

• Data from all sources (load, AE, AU, microscopy) were used in an attempt to describe the various classes.

• Description of significant classes.

CONCLUSIONS

•AE can provide vital information about mechanisms in mortar and concrete specimens (preliminary tests on concrete have been performed).

• AU can provide information about the behaviour of concrete under load and sustained damage.

• Pattern Recognition is key tool in manipulating very complex data and allows easier correlation of various techniques' results.

• AE and AU results when combined can provide enhanced insight to concrete fracture mechanics.

• Combination of results may provide a means to assess concrete status.

• Problem is very complex due to concrete nature, so much experimentation is needed.

• Next steps : Further analysis, concrete specimens.

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For details refer to :

Damage Level Evaluation and Characterization by Acoustic Emission and Acousto-Ultrasonics in Concrete Under Compressive Loads

15th World Conference on Non-Destructive Testing, Rome, Italy, 15-21 October, 2000

Apostolos Tsimogiannis, Barbara Georgali. Dr. Athanassios Anastassopoulos

Aerial Manlift Device Testing

Acoustic Emission Testing of Aerial Manlift Devices to characterize possible damage in Metal and FRP sections.

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ASSUMPTION & LIMITATIONS OF CONVENTIONAL ANALYSIS:

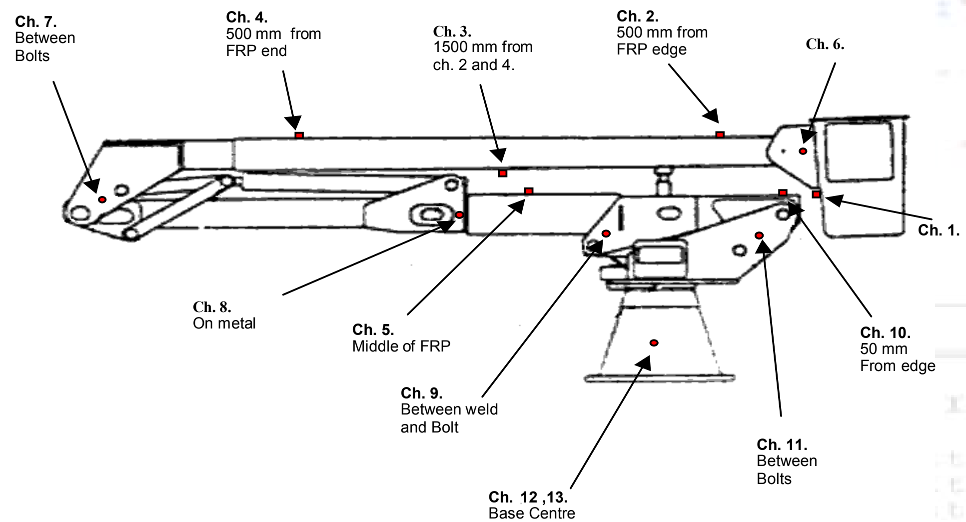
Evaluation criteria are based on filtered data, where noise sources are identified and filtered.
Lack of universal analysis methodology, independent of the specific device.

SCOPE

⇒ **Establish analysis methodology by means of Unsupervised Pattern Recognition**, aiming to enhance analyst efficiency in discriminating the different AE Sources.

⇒ **Automate noise discrimination and evaluation for similar devices and test conditions** by means of Supervised Pattern Recognition and Neural Networks.

EXPERIMENTAL SET-UP

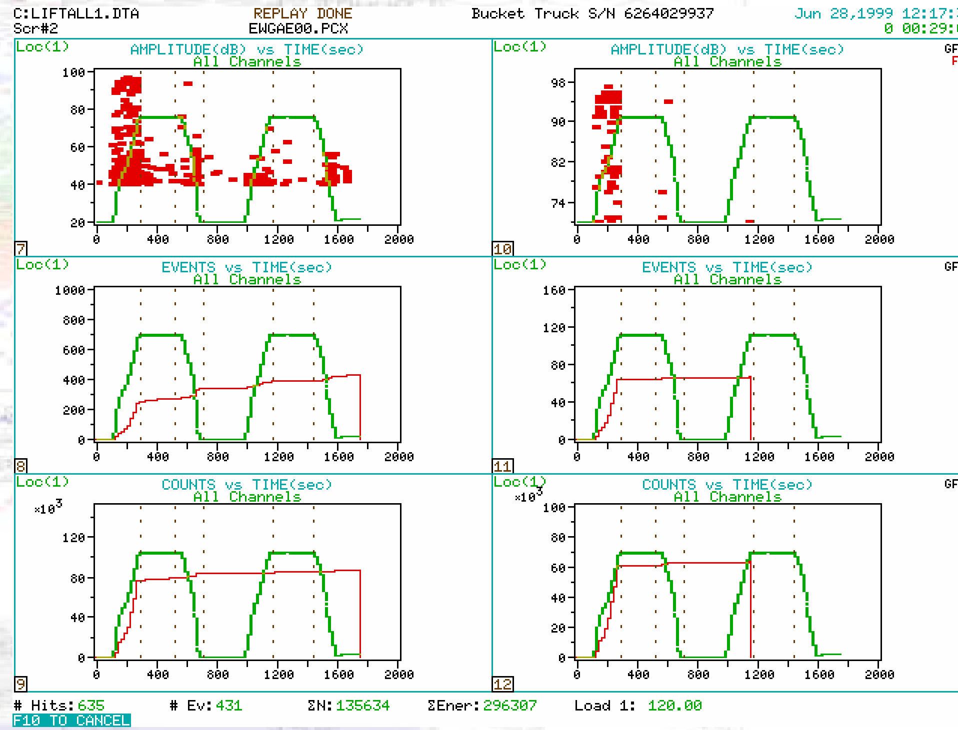


Sensors position and overall assembly of the device.

Channels 1 to 5 were attached to the composite/insulated parts, Channels 6 to 13 were attached to the metal parts.

Aerial Manlift Device Testing

Traditional AE Analysis: **Real Time Plots for Emergency Test Termination**



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Aerial Manlift Device Testing

Unsupervised Pattern Recognition - Parametric Study:

Estimation of # of Classes & Results Optimization. Cluster validity based on further AE analysis via location and other techniques.

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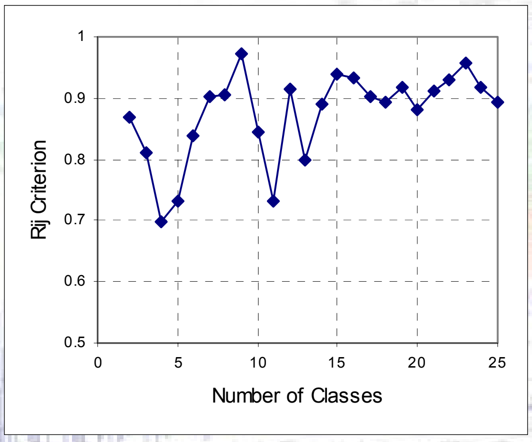
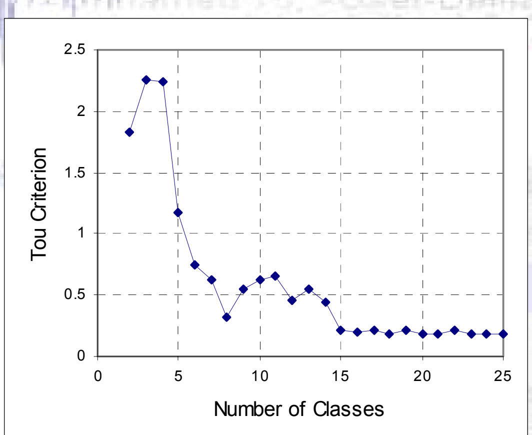
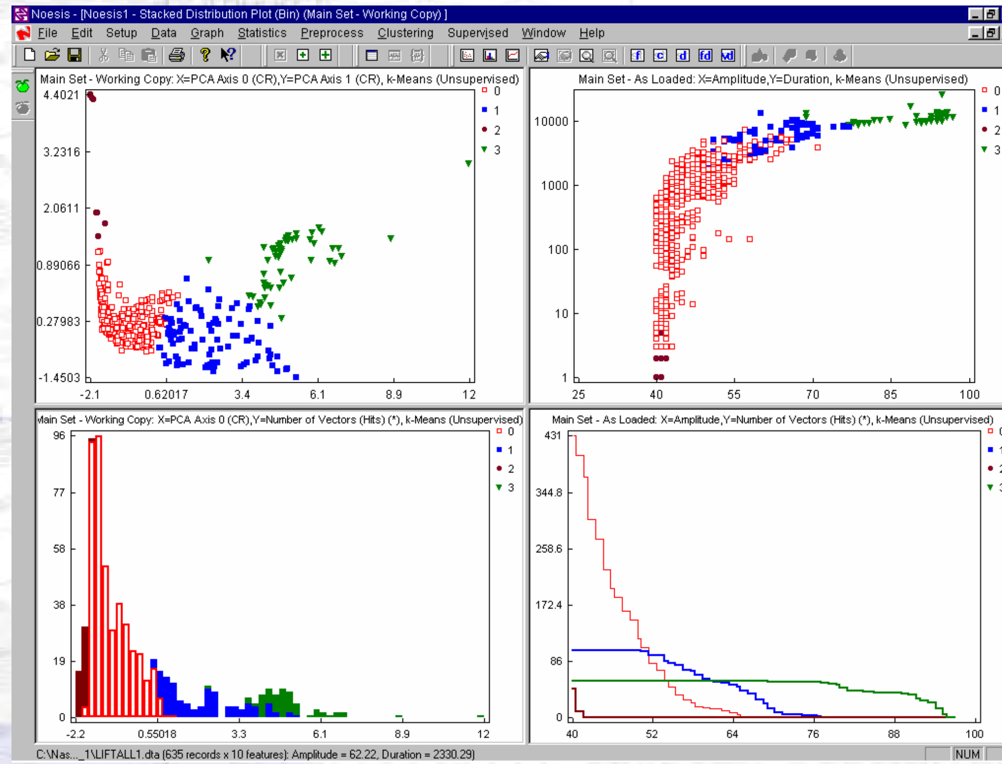


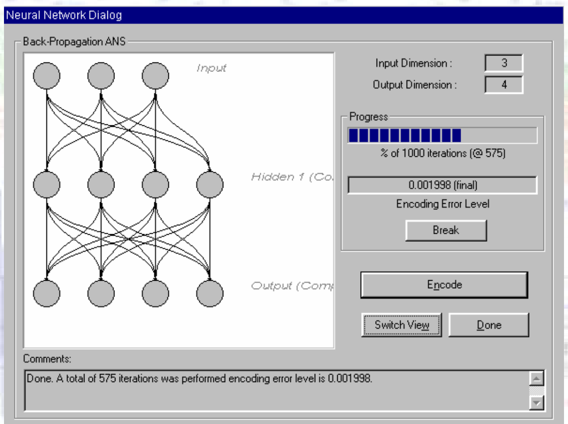




K-Means Clustering Algorithm: Data Partition in 4 Classes

Aerial Manlift Device Testing

Supervised Pattern Recognition Training and application to other device data.



A Back Propagation Neural Network was trained with the derived classification. The net topology is shown below along with the results from application of the SPR to data from other aerial manlift devices.

CONCLUSIONS-RESULTS

•Class discrimination by UPR resulted in verified classes for various signal types.

•Further application by SPR to new data showed successful discrimination of noise resulting from hydraulic actuators, acoustic emission from metal parts and acoustic emission from FRP parts.

NOESIS

For details refer to :
Acoustic Emission Proof Testing of Insulated Aerial Manlift Devices
European Working Group on Acoustic Emission Symposium, Paris, France, 24-26 May, 2000
Dr. Athanassios Anastassopoulos, Apostolos Tsimogiannis, Dimitrios Kouroussis.

Metal Pressure Vessel Data Analysis

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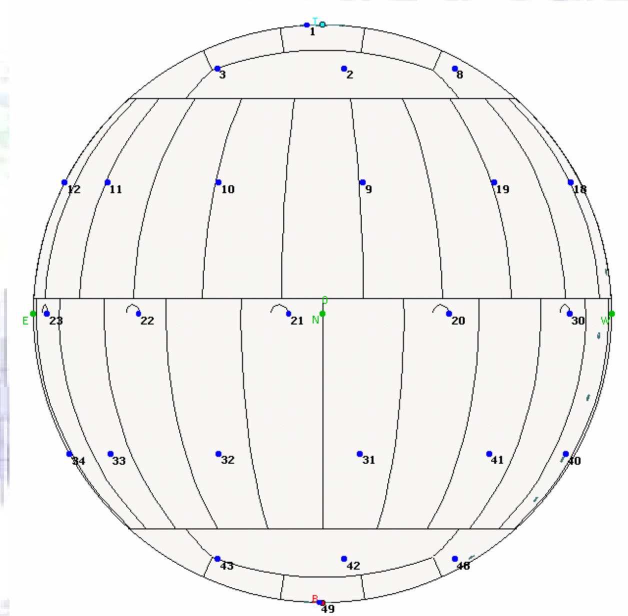
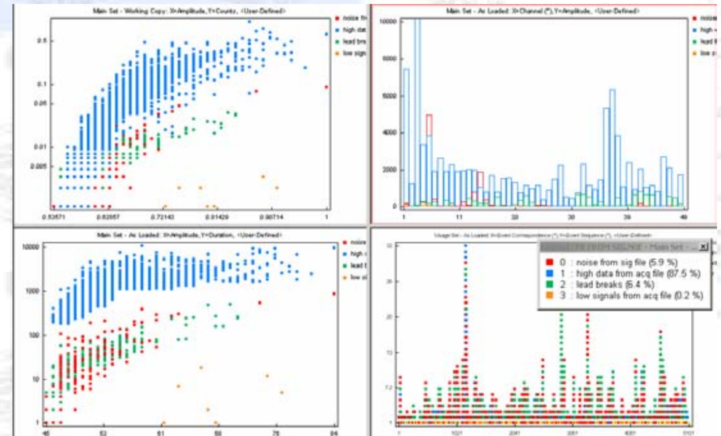
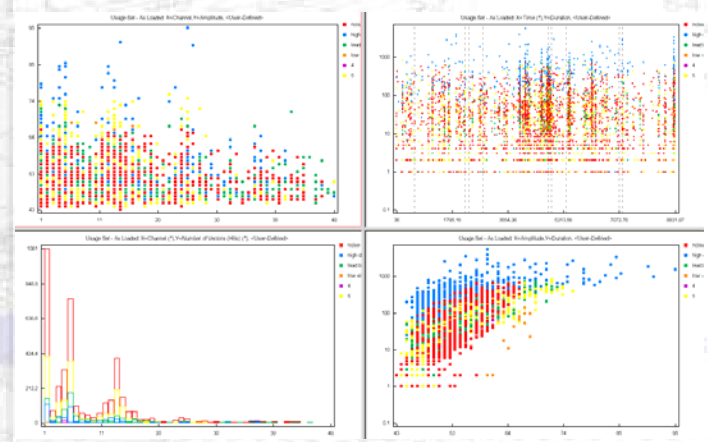
Noesis is extensively used for the analysis and signal discrimination in real applications on metallic pressure vessels and tanks.





Signature analysis and SPR creation for application to unknown data for noise discrimination and data analysis and filtering.

Noesis was successful in discriminating data in complex cases where traditional analysis could not yield acceptable results.

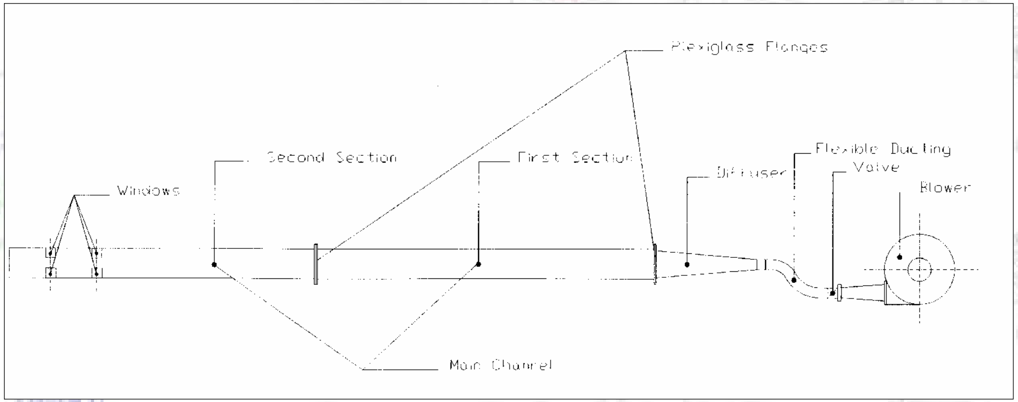


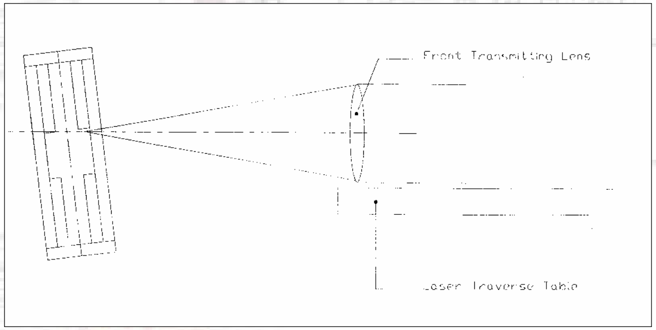
Application of SPR process to unknown data.

For details contact Envirocoustics at :
info@envirocoustics.gr

Application of Noesis on Laser Doppler Anemometry Data

•**Data Used**: Three-component Laser Doppler Anemometer Data from turbulent air flow measurements on a closed, compound channel.





For each point in the flow the following parameters were measured: $(U, V, W, \overline{u^2}, \overline{v^2}, \overline{w^2}, \overline{uv}, \overline{uw}, \overline{vw}, \Omega_\chi)$

where $\Omega_\chi = \frac{\partial W}{\partial y} - \frac{\partial V}{\partial z}$ is the axial vorticity

UPR was applied by NOESIS using K-Means.

The corresponding feature set was reduced to: $(\overline{u^2}, \overline{v^2}, \overline{w^2}, \overline{uv}, \overline{uw}, \overline{vw}, \Omega_\chi)$

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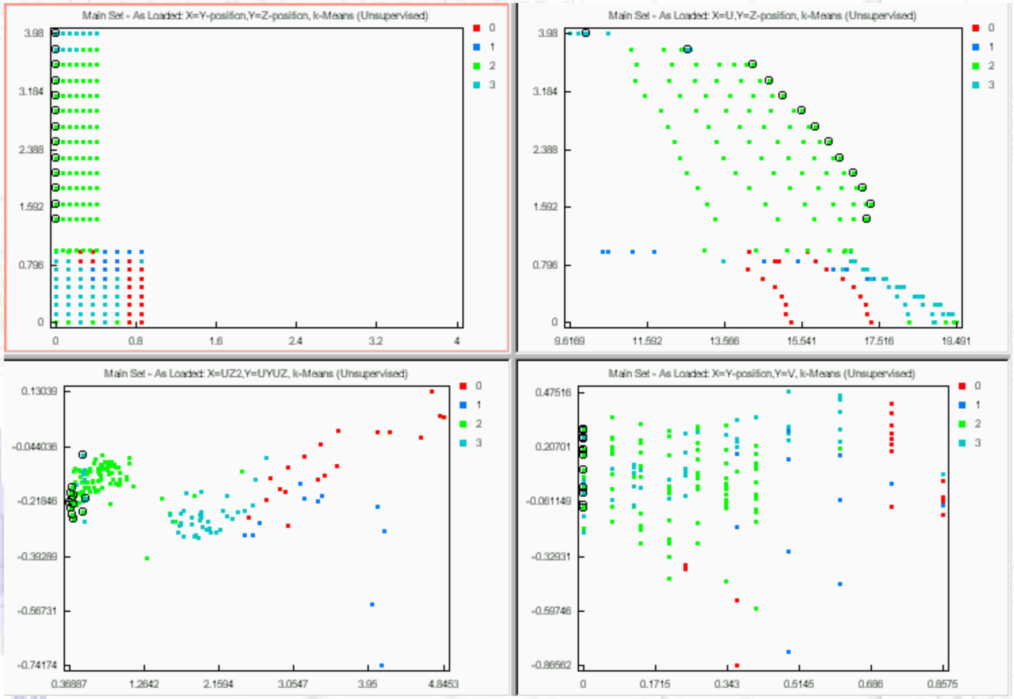
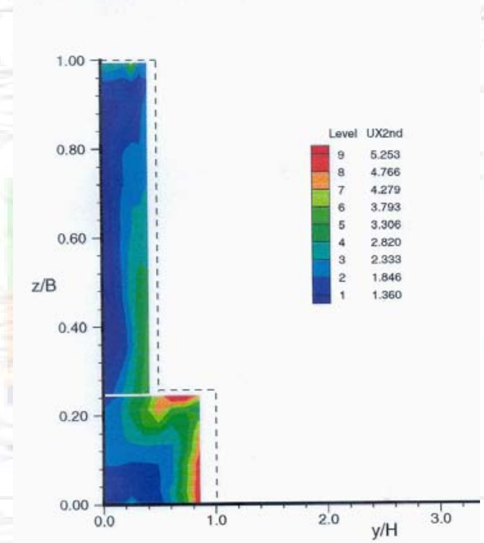
Application of Noesis on Laser Doppler Anemometry Data

NOESIS results



"Conventional" analysis results (vorticity contours)*



* Kouroussis, D. A., "An Experimental Investigation of the Turbulent Flow in a Closed, Compound Channel", M.Sc. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, U.S.A., February 1996.

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RESULTS / CONCLUSIONS

- Enhanced **insight** on the data revealed hidden turbulence patterns
- **Automated filtering** of LDA single point data with supervised pattern recognition
- **Identification** of high dissipation and high entropy production regions in a flow
- Development and **evaluation** of turbulence models
- LDA **waveforms processing**

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