# The Application of Adaptive Systems in Condition Monitoring


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## ABSTRACT

This paper provides an overview of four large collaborative projects, which are currently being undertaken by the Centre for Adaptive Systems at the University of Sunderland. The projects utilise adaptive system technology to solve condition monitoring problems, and are funded from a variety of sources including UK Government agencies and the European Union (EU). Each of the projects is very strongly problem and industry driven and aims to produce real results for the benefit of companies.


## 1 INTRODUCTION

The Centre for Adaptive Systems at the University of Sunderland is working on a large number of collaborative research and development projects. These projects apply adaptive system technology, including neural networks, artificial intelligence and genetic algorithms to solve industrial and business problems, including several condition monitoring problems.

The Centre for Adaptive Systems brings together skills from within the University of Sunderland including artificial intelligence, fuzzy systems and control engineering. The Centre currently comprises six academic staff and 10 research assistants. The projects within the Centre are funded from a variety of sources including UK Government agencies and the European Union (EU). This paper presents an overview of four of the projects, which are currently being developed within the Centre. As such it gives an indication of the potential of adaptive system technology for solving condition monitoring problems.

The projects covered in this paper are:
- VISION
- NEURAL-MAINE
- ATLAS
- Vibration Case Library

## 2 VISION (Vibration Interpretation using Simulation and the Intelligence of Networks)

VISION is a collaborative project, part-funded by the EU BRITE-EURAM programme. The aim of the VISION project is the development of an intelligent vibration monitoring system, linking simulation, neural networks, and other artificial intelligence techniques.

The project partners are:

- Monition Ltd
- VTT Manufacturing Technology
- University of Sunderland
- Carnaud Metalbox
- Nestlé UK
- ABB Service Oy
- Marine Corporation of Lesvos SA
- National Technical University of Athens

The objective of the VISION project is the development of an intelligent, adaptive monitoring and diagnostic system, based on artificial intelligence and simulation modules, which will analyse engineering data, specifically vibration spectra, in order to sustain a high level of equipment reliability. The artificial intelligence will come from the integration of neural networks, neuro-fuzzy systems, and knowledge-based system techniques. The results from the VISION Project could reduce time consumed in data analysis by over 90%, giving potential savings of up to 60 MECU per annum in this aspect alone. Additional benefits will come in the form of improved accuracy of prediction and less wasted effort in removing machinery unnecessarily (which is estimated to occur on 11% of the occasions where action is taken as a result of vibration analysis). The project will also reduce maintenance-induced faults (estimated to be more than 50% of all mechanical defects).

It is anticipated that the products which will eventually be developed from the results of the VISION project (12 to 18 months after project completion) will provide European industry with valuable tools which will aid not only their competitiveness, but will also have positive environmental and social impacts. The project consists of a large element of computer simulation. In order to create a truly generic solution to vibration analysis a mathematical model of a simple piece of plant has been developed. This model will serve as a platform on which to build more complicated models as the project progresses.

Figure 1 shows the relationship between the simulation module and the diagnosis module in the VISION system.

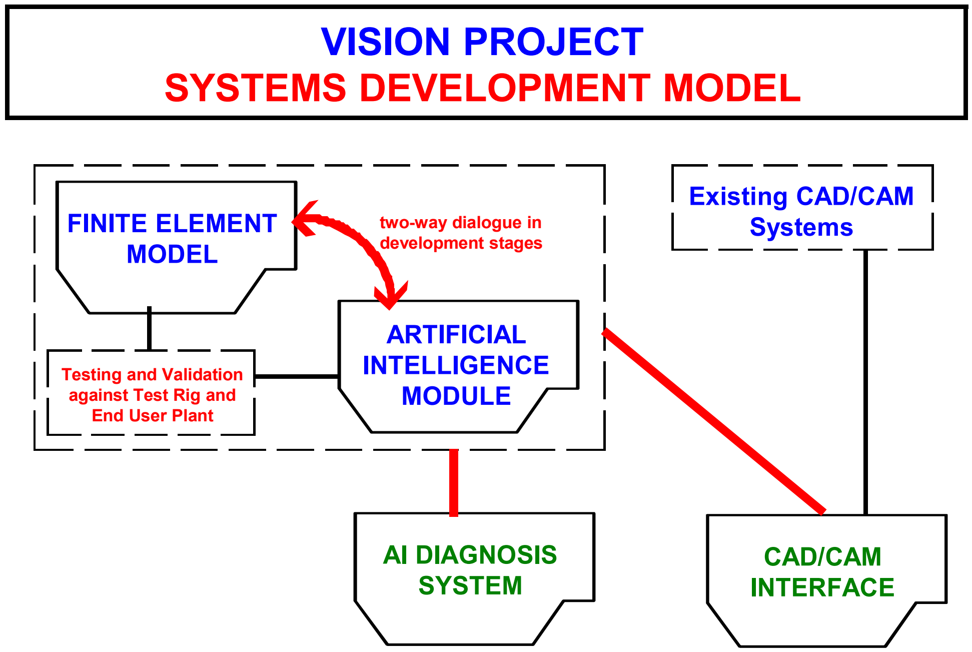


**Figure 1 - VISION Module Hierarchy**

The first phase of the project involved the construction of a simple test rig (see Figure 2). This initial work commenced in parallel with developing a Finite Element Model (FEM) of the test rig (developed by VTT). This model is a computer simulation of how a simple drive motor coupled to a load motor would behave under variable loads and speeds. Once the actual test rig was in operation a series of faults were introduced and the vibration spectra gathered were used to update and refine the FEM simulation.

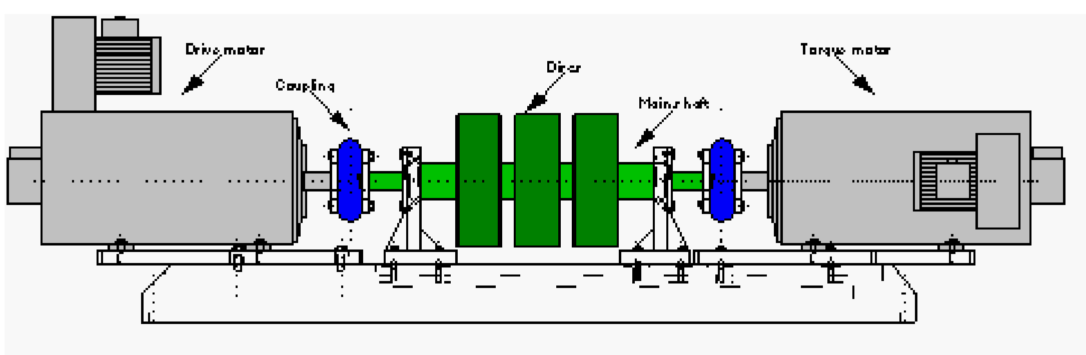


**Figure 2 - The VISION Phase I Test Rig**

The work carried out by the University of Sunderland is concerned with the analysis of the data produced by the FEM model and the vibration data gathered from the test rig. The end result of this analysis is to produce an intelligent diagnosis system capable of recognising a range of faults occurring both singly and in multiples. The data consists of parameters, which are in effect a subset of the vibration spectra. Rather than deal with the entire vibration spectrum frequencies have been selected that are believed to be necessary for effective fault diagnosis. A range of statistical tests and neural network models has been produced and these have identified known parameters and previously unknown relationships. Figure 3 shows the general flow of simulated, test rig, and actual plant data, with selection of parameters and the application of the eventual hybrid intelligent analysis system.

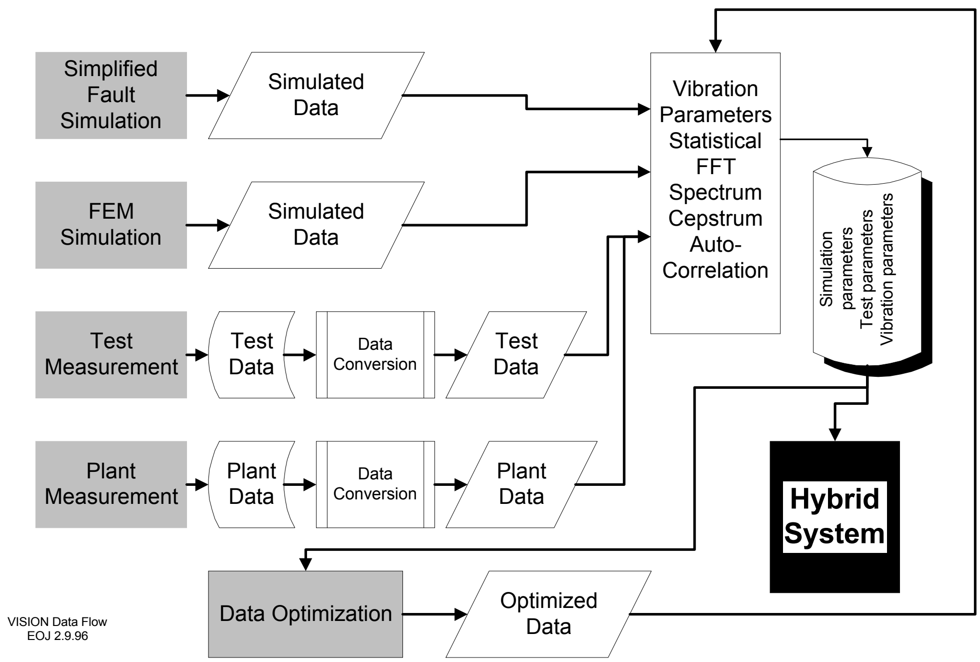


**Figure 3 Overall Diagnosis System Integration**

## 3 NEURAL-MAINE

This EUREKA project concerns the condition monitoring of complex rotating machinery.

The project partners are:

- The University of Sunderland
- Brunel University
- Monition Ltd.
- National Power
- Neural Computer Sciences
- The Royal Mail
- Leatherhead Food Research Association
- Bruel & Kjaer (Holland) - co-ordinator for a group of Dutch partners

Failure of a critical machine, such as a turbo-generator unit, mail processing unit or food processing unit will result in expensive downtime, and financial or even human loss. Plant operators need to know in advance when a machine component is starting to deteriorate and how long it will be before a total failure occurs, so that a repair schedule can be created and replacement parts acquired for the repair. The NEURAL-MAINE project (EUREKA 1250) aims to advance the technology available for complex machine diagnostics by the use of multiple sensor technology, data fusion and neural networks.

The project aims to solve these problems by reducing the complex task of monitoring a large machine into smaller subcomponents called Local Fusion Systems (LFSs). These LFSs will take local machine component data and fuse these data into one model which represents the normal operating state of the machine. Once trained, new data will be passed through the neural network to see if they are recognised as normal, or novel. If the data are recognised as novel, then a local diagnosis will occur to try and establish what the problem is. These problem data and other states will then be passed up to an "overseer" system. The overseer system will sit above all of the LFSs and take, as input, their output as well as global plant parameters. It will then use Artificial Intelligence (AI) techniques to decide upon the status of the entire machine.

Work on the LFS has taken place as a continuation of Taylor's (1996) work. Taylor's previous work had investigated the use of the Kohonen SOM (Self-Organising Map) in the application of the LFS. Taylor (1996) successfully showed that a Kohonen SOM could be used as a novelty detector for a condition monitoring application by placing one threshold value around the data space. However, although this model worked on simple examples, more complex data were giving false negative detections. As a result of this work a new architecture was developed which enables local level diagnostics and on-line learning to be carried out. The overall architecture of the NEURAL-MAINE system is shown in Figure 4.

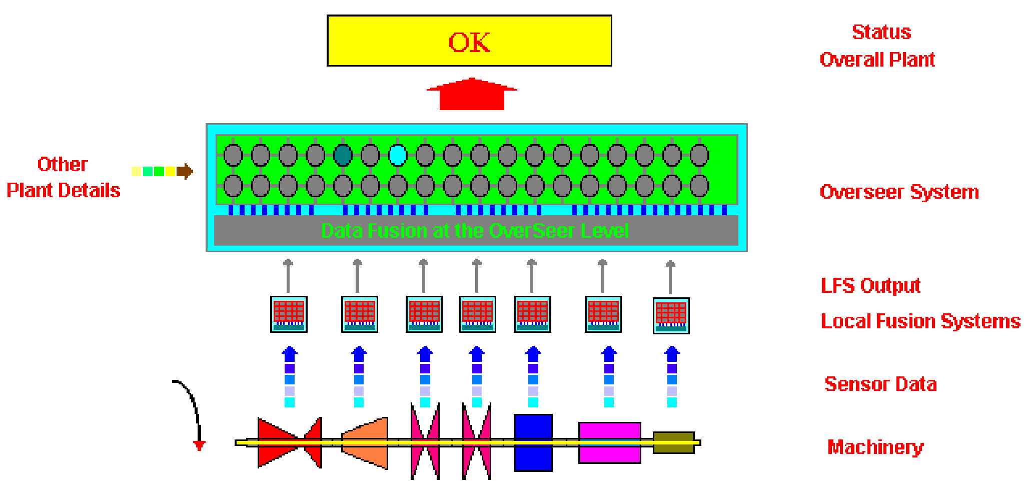


**Figure 4 - The Overall NEURAL-MAINE Architecture**

The LFS will allow prior knowledge to be added in the cases where complex machinery systems are in use; for example steam turbines. A lot of knowledge exists about the factors that occur when a certain fault is developing (e.g. oil whirl, misalignment, etc.). This knowledge can be used to create a synthesised data set, which in turn will be used to train the diagnostic network of the LFS. A Kohonen map will be trained with the fault data and the relevant areas relating to the specified faults will be labeled accordingly, as shown in Figure 5.

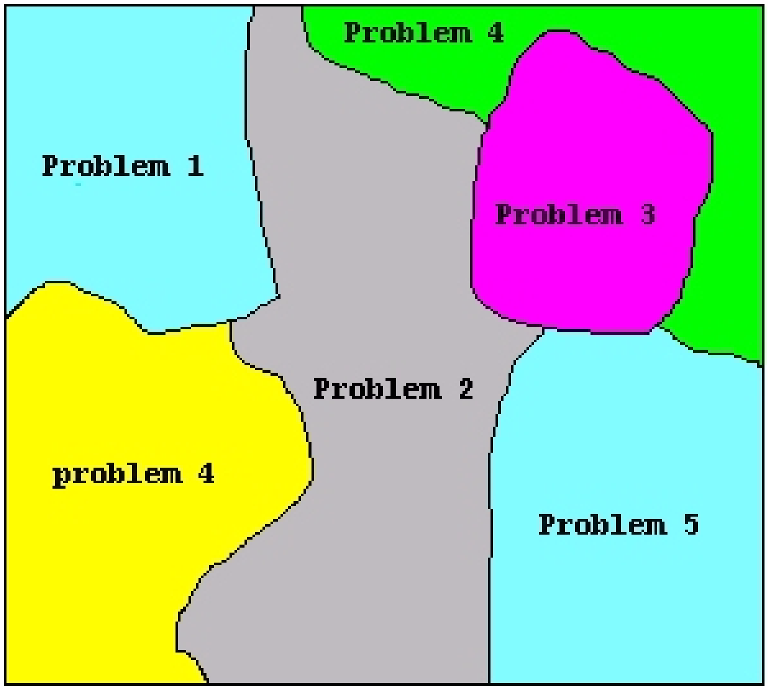


**Figure 5 - Labeled areas of a Diagnostic Kohonen Map**

A strategy for dealing with new data, and therefore allowing dynamic learning, has been developed, using a stack of Kohonen networks. This strategy is being developed further in the current stage of the project.

Testing has been carried out on the new architecture (Maxwell, 97) with data from National Power Blyth. The project proved that the new novelty detector was more robust than the earlier prototype (accuracy levels of 98%), and that the idea of using a second diagnostic network worked well. The fault conditions were generated synthetically to show problems that could occur on a large steam turbine.

Future work will look more closely at improving the novelty detector, improving the new LFS architecture and testing the architecture on a variety of different condition monitoring applications including mail processing machines, gas turbines and a variety of food processing machines. Work will also be carried out on the dynamic on-line learning module, which forms the final part of the LFS.

# 4 ATLAS

The objective of the ATLAS Project is the development of an intelligent on-line monitoring system for detecting and locating steam leaks in industrial pipework. The overall aim of the project is to develop a low-cost solution to the problem of automated leak detection and location in a variety of industrial situations, such as steam boiler tubes, condenser tubes and high-pressure steam pipework.

The project partners are:
- Holroyd Instruments Ltd.
- University of Sunderland
- Allen Consultant Engineering Ltd.
- National Power plc (Blyth Power Station)
- Cleveland Potash Limited

The project is part funded by the Department of Environment under the Energy Efficiency Best Practice Programme.

A test rig has been set up at Blyth Power Station to enable testing of the prototype system. At Cleveland Potash part of a steam line has been set up to enable experiments to be conducted on a live system. This has allowed testing to be conducted in the real world to determine the optimum frequency for detecting leaks, or Signal to Noise Ratio (SNR), attenuation rates and other statistical features of the acoustical properties of leaks.

Using these results, intelligent sensors have been developed which capture the waveform and extract features. The sensors are secured onto wave-guides, which are attached to the steam line. A multi-channel data capturing software package has also been developed to allow the capture of simultaneous real time signals from the sensors.

Software for analysing the data off-line has been designed to allow experiments to be carried out to explore various techniques, including neural networks, for both leak detection and leak location. A Graphical User Interface (GUI) has also been developed as a front-end for the final product. The front end works off-line but has been set up to run as if the data are on-line and has been integrated with the analysis software.

The hardware for data capture has been developed and the final system will have a dedicated minicomputer, daisy-chained intelligent sensors, software and a power supply. Immediate future plans are to complete software integration. This will then allow on-line testing of the system to verify that it does not trigger false alarms and can detect leaks when they do occur.

Further analysis work will be undertaken to test and refine the leak location method and to investigate other possible on-line learning techniques. For the software, data management criteria are to be determined and implemented and the software will be fully evaluated by the end-users.

## 5 VCL (Vibration Case Library)

This project aims to develop a case-based reasoning (CBR) tool for vibration analysis. The objective is to demonstrate the use of a CBR approach to condition monitoring using vibration analysis, where rule-based systems have hitherto performed poorly and hybrid intelligent approaches have had limited success.

The project partners are:

- Monition Ltd.
- University of Sunderland

The software has been developed using Microsoft Visual Basic, Visual C++, LPA Win-Prolog, and Microsoft Access. The biggest design decision was to use a database for the case manager. This is a very under researched area in CBR, with the exception of the work of Shimazu and Kitanu (1993).

A lot of work has been carried out with respect to case authoring. Figure 7 shows the form in which the company currently records its analysis, on paper, along with the corresponding spectra, which are stored electronically.

The user builds up the query machine configuration by means of a “drag and drop” interface, and indicates where the measurement point is from which the spectra has been recorded.

The details of the machine part where this measurement occurs are also input if known. These constitute the initial search criteria: the configuration and machine part details. At a later date these will also include spectral information.

At present the user is presented with the nearest (n) stored machine configuration(s) and he/she can compare his/her spectra with the retrieved spectra, and read the “history” of the case. If there is not an exact match for the whole configuration, then the search criteria are a subset of that configuration, each time becoming smaller until only the machine part from which the spectra was taken is searched for.

At the present time we are converting cases into the case library format. A lot of work has been conducted with regards to the representation issues, not only of the different configurations, but also the important features of machine types, these being vital for a useful similarity metric. For instance with fans, the important features are number of blades, impeller speed, etc.; each of which affects the similarity between machines in a different way. A representation language for spectral faults is also under development.

Future similarity metrics will also take into account spectral information. A language will be developed to describe (in predicate logic) the information contained in the “history” text, so that the issue of adaptation can be addressed. When a large case-library has been developed this will shed light on the performance of the retrieval algorithms, and issues such as optimum size of case base, maintenance of case base, etc.

## 6 SUMMARY

This paper has presented an overview of four projects currently being undertaken by the Centre for Adaptive Systems at the University of Sunderland. The projects all apply adaptive and knowledge-based technology to the solution of condition monitoring problems.

## Acknowledgements

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