EARLY WARNING OF CRITICAL FAILURE IN COMPLEX SYSTEMS

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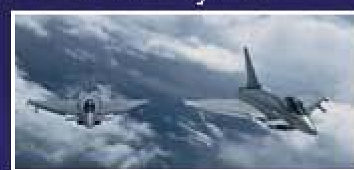
The Need for Early Warning

Critical failure in complex systems (such as jet engines, industrial power plants, and manufacturing processes) may result in *extreme hazard* to humans and environment.

Critical failure can result in *extreme cost* due to interruptions in service – such systems must have minimal "downtime".

Intelligent, new techniques are required by industry to give early warning of critical failure, exploiting the large quantities of data available from modern systems.



Novelty Detection

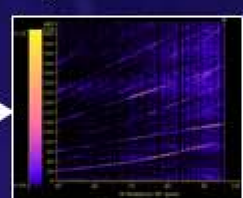
Examples of failure in critical systems are rare in comparison to large amounts of available normal data.

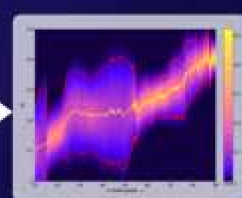
Due to high system complexity, early signs of critical failure are often ill-defined or ill-understood, limiting the use of conventional *fault detection* approaches.

Novelty Detection exploits this situation by identifying deviations from a *model of normality*. Early warning of failure is given by identifying precursor abnormal events.

Machine Learning Algorithms for Automatic Novelty Detection

Constructing Probabilitistic Signatures





High data sampling rates make very large "normal" data-sets, several TBytes in size.

Data size is reduced to tractable levels by extracting *features*.

We construct *signatures* that define "normal" behaviour of features (*y*-axis) over an operating variable such as speed (*x*-axis), in terms of probability.

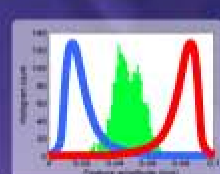
Training a Model of Normality

Signatures of different types of data are combined using *data fusion* to provide a "holistic" model of system normality. This allows robust and reliable alerting in the presence of noisy or incomplete data.

On-Line Novelty Detection

On-line analysis (such as in-flight jet engine monitoring) must operate in *real-time*, and use minimal storage and computation resources.

We have developed a novel statistical method Using *Bayesian reasoning* for modelling the "abnormal" region of the feature range, given our detailed knowledge of the "normal" region.



Data are compared to the model sample-by-sample, providing a *combined probability* that the system is "abnormal". Our probabilistic approach gives us the key advantage of determining *confidence* in generated alerts.

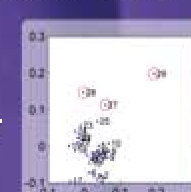
Proven using 6 months of developmental flight data of the Rolls-Royce Trent 900 jet engine (powering the Airbus A380), the Oxford system gave early warning of events of up to 1.5 hours, with minimal *false-positive* alerting during the trial. This compares favourably with conventional techniques, which showed little early warning capacity combined with a high false-positive rate.

Off-Line Novelty Detection

Off-line analysis (such as ground-based tracking of jet engines) must operate *without access to full data*. A flight must be summarised using small data structures for transmission to ground-based stations.

We perform automatic flight-by-flight novelty detection by constructing a model of normality from these signatures using an extended *Support Vector Machine* algorithm.

Users need visual feedback to have confidence in automated monitoring. Intuitive tracking of engine condition is provided by training a *neural network* to display each flight as a single point.



Using similar techniques, we have created visualisation tools allowing users to track a *fleet* of engines, or view a *timeline* of engine condition throughout its service life. These allow communication of highly complex system models in an understandable manner.

Commercialisation

Patents

1 patent pending in 2006, 2 patents in commercial discussion.

Products

Implemented by Oxford BioSignals Ltd. as a range of analysis tools.

Aerospace

Adopted by Rolls-Royce for monitoring in Airbus A380, Eurofighter Typhoon, and Boeing Dreamliner.

Generic Application

The generic application of this work is emphasised by successful commercial collaborations with Jaguar, DS&S (energy sector), ABB (ship turbochargers), a second unnamed automotive company, and an unnamed manufacturing company.