Remote Machine Condition Monitoring

Dr. Iqbal Gondal

Photo: Ute Kraus

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Acknowledgements

- Associate Professor Joarder Kamruzzaman
- Dr. Farrukh Yaqub
- Dr. Campbell Wilson
- Mr. Muhammad Amar
- Mr. Hua Xueliang (Nevo)
Condition monitoring

- Introduction
- Frame work for remote equipment condition monitoring and our work
- Our expertise and studies on condition monitoring of machines
- How can we help!
Perception and Trends

• Equipment manufacturer wants to reduce time-to-market, maintain flexibility and sustainability in products over long periods.
• Users desire high up-times, quick resolution of faults
  – Remote condition monitoring and predictive maintenance enables just that!
  – Condition monitoring is an insurance policy for equipment reliability
In modern industrial operations condition monitoring should help to manage site plant assets, logistics and labour requirements.

Condition monitoring can be two types:

- Offline: data logger collects the data and then analysis is done offline.
- Online monitoring: permanent connection to the equipment.
  > Surveillance monitoring: Between off line and online.
    - In Surveillance monitoring intervals can be increased without incurring additional labour cost. This allows for better fault detection, and permits collection from dangerous or hazardous areas without incurring risks to engineers.
  > Continuous online monitoring: permanent data logger and transmitting the data to data analysis facility.
    - There is no time lag, and full protection to the asset can be provided.
Nature of Faults in Industrial Environment

• It is estimated that 77% of all mining accidents resulting in fatality have occurred involving equipment.
• Design and fit-of-purpose of equipments is very important aspect to be analysed to reduce the fatalities
• Industrial processes contain a network of hundreds of equipment to transform inputs to outputs
  – For successful operation
    > Importance of some specific equipment is far more vital than others,
    > Rigorous monitoring of these equipment should be priority
• Equipment rank could be based on:
  – Effect of equipment failure on the process, cost of replacement, health and safety, environmental consequences …..
Remote Equipment Condition Monitoring

- **Monitoring sensors**
  - Sensor information processing

- **Remote Access**
  - Sensor networks
  - Communication networks
  - Coexistence of Multiple Networks

- **Machine Condition Monitoring**
  - Vibration Patterns, acoustic signals, transients in power supply
  - Fault Diagnosis under Poor Signal to Noise Ratio
  - Fault Severity Estimation Analysis
  - Residual life prediction
Remote Condition Monitoring benefits

- Crucial in all industrial processes to achieve:
  - High reliability
  - Reduced man power
  - Scheduled maintenance
  - Unscheduled maintenance costs is reduced – Condition monitoring
  - Improved Plant Visibility
  - Reliable Transfer of Information
  - Centralized Decision Making-Ensuring optimality.
**RMCM Framework**

- Sensors and co-existing networks
- Digitized sensor data
  - Vibration data
  - Acoustic data
  - Transient (current) from power supply
  - Oil analysis
  - Infrared thermography
- Signals analyzed using:
  - Wavelet transform (WT)
  - Fast Fourier Transform (FFT)
- FFT and WT helps in investigating the frequency contents of the recorded data in different frequency ranges, i.e., sub-band.

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**Diagram:**

1. Vibration Data
2. Wavelet Transform
3. Higher Order Cumulants (HOC)
4. Prominent Features Extraction
5. Classification
Our work in Sensor networks

• Sensors should be able to make ad hoc wireless networks
• Sensors should be able to self configure to form an intelligent network
• Conserve energy and prolong life time of sensor networks
• Form clusters to make intelligent collaborative decisions
• Sensors should be cheap and light weight
• Sensors should be able to rotate roles from sensing to cluster head
• Sensors should be able to form a virtual back bone in sensor networks for efficient routing and distant communication
• Sensors should minimise the data amount, they need to send
• Sensor should be able to access medium intelligently using Omni and directional smart antenna
• Sensor should be durable to operate in hostile environment
Real time data mining

- Features are extracted by calculating the
  - root mean square (RMS) values for different nodes after wavelet decomposition
  - Sample mean and variances are computed as features after decomposition of the data
  - Features are extracted by computing kurtosis, i.e., 4th order standardized moment
  - Energies for different sub-bands as the features for classification
  - Higher order cumulants (HOC) for each node

- Classification
  - KNN
  - SVM
  - NN
The recorded fault signal is transient in nature so detection of abnormality by observing single vibration value is not possible
  – Need temporal data

Feature extraction is necessary for dimensionality reduction in case of fault data before classification because important information for classification lies in much reduced dimensional space.

To guarantee the improved performance of the proposed system under poor signal to noise ratio, higher order statistics (HOS) are employed. HOS have the tendency to eliminate the impact of Gaussian noise, the major component of noise in most of the physical systems.
Remote Access in co-existing networks

- **Coexistence**: “the ability of a network to perform EFFECTIVELY in the existence of other networks using same band of frequencies”.

- Increasing number of coexisting networks in Industrial, Scientific and Medical (ISM) band could cause **static and self interferences**
  
  - Sufficient frequency diversity (irrespective of the number of coexisting piconets) and the capacity to differentiate the channels as ‘good’ and ‘bad’ in a relatively shorter time without any extra overhead
  
  - Capacity to stop transmission on the frequencies, causing repeated packet loss
MCM: Fault Diagnosis under Poor Signal to Noise Ratio Framework

- Adaptive feature extraction mechanism was developed to enhance accuracy.
- Feature extraction based on statistical parameters

![Diagram]

1. Vibration Data
2. Stationary Wavelet Transform (SWT)
3. Higher Order Cumulants (HOC)
4. Prominent Features Extraction
5. Classification

![Graphs]

- Classification Accuracy vs. Signal to Noise Ratio (dB)
- Different classes (inner, ball, outer) are shown
Faults belonging to different severity levels causes class overlap for the faults belonging to different types.

An adaptive model is proposed which help out the classifier to diagnose the fault independent of the fault severity.

The classification accuracy for the proposed scheme is 93% and number of features is from 62 to 17
Adaptive training for the classifiers for fault detection

- The training set of data samples with different severity levels and significantly diverged orientation of the data samples may mislead the classifier to establish the hyper plan (boundary) wrongly for the faults of different types
- Adaptive selection of the training data points for every new test to be conducted
- Adaptive feature selection
- SVM as classifier

Results for minimum and average accuracy:

- Without ATSFS: 7.00% - 39.33%
- With ATS: 47.0% - 56.33%
- With AFS: 31.0% - 42.49%
- With ATSFS: 63.0% - 70.67%
Severity estimation helps in measuring the residual life.

Continuous monitoring and if severity level exceeds a certain threshold, equipment may be replaced.

The points in the accompanying figure correspond to **four different severity levels for inner race fault** (one of the types of bearing fault).
Anomaly Detection for Ubiquitous Safety

The output is compared with a safety threshold to give an anomalous condition alarm.
Smart Phone Based Machine Condition Monitoring System

Usage of Smart Phone

- Data Acquisition
- Signal Processing Capabilities: WPT, RMS
- Fault Diagnosis: KNN
- Data Logger

- Normal Laptop
- Fan Fault
- Loose keyboard and associated vibrations.
Smart Phone Application:

- Smart Phone Vibration data is acquired using the built-in accelerometer.

<table>
<thead>
<tr>
<th>Table 1. Performance Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Data</td>
</tr>
<tr>
<td>Brand-new</td>
</tr>
<tr>
<td>Keypad looseness</td>
</tr>
<tr>
<td>Fan fault</td>
</tr>
</tbody>
</table>
Immune system and condition monitoring

• Industrial operations can be considered like human body
  – Vital equipment ↔ crucial body organ e.g., lungs, heart, kidney, liver
  – Remote condition monitoring ↔ Human brain and nervous system

• But condition monitoring-diagnosis-prognosis should be flexible and generic to cater for variety of industries
Mobile Agent Based Artificial Immune System for Machine Condition Monitoring

- Big industrial processes are distributed over large geographically distant areas,
  - For remote condition monitoring, a large amount of data needs to be transmitted and managed
  - Rather than transporting the data, why not mobile agents should visit the site and process the data
For mobile agent based architecture to machine condition monitoring,

- We imitate human immune system using Clonal Selection Algorithm (CLONALG)

- Wavelet packet transform (WPT) and root mean square (RMS), are used to perform feature extraction

- Support vector machine (SVM) is used to conduct classification
Condition monitoring vs Immune system

<table>
<thead>
<tr>
<th>immune system</th>
<th>mobile agent based AIS</th>
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<tbody>
<tr>
<td>B-Cells</td>
<td>BCell - mobile diagnosing agents</td>
</tr>
<tr>
<td>T-Cells</td>
<td>TCell - mobile diagnosing agents for co-stimulating BCell agents</td>
</tr>
<tr>
<td>Antigens</td>
<td>Vibration data feature vectors</td>
</tr>
<tr>
<td>Affinity</td>
<td>Classification accuracy of given feature vector</td>
</tr>
<tr>
<td>Clonal selection</td>
<td>Clonal Selection Algorithm</td>
</tr>
<tr>
<td>Immune memory cells</td>
<td>Generated agents through Clonal Selection Algorithm</td>
</tr>
<tr>
<td>Mutation</td>
<td>Feature selection</td>
</tr>
<tr>
<td>Cell clone action</td>
<td>Agent clone action</td>
</tr>
<tr>
<td>Cell circulation</td>
<td>Agent migration</td>
</tr>
</tbody>
</table>
Our expertise

- Remote condition monitoring
- Social connectivity driven systems and services
- Wireless technologies
- Sensor networks
- Intelligent networks and system
- Mining of complex temporal sensor data
- System simulation and performance evaluation
- Prototyping
- Or any specific problem in these domains
Conclusion

- Equipment maintenance could be devised based on condition monitoring
- No fixed maintenance schedules
- Save money
- Estimate uncontrolled failures in advance
- Better use of maintenance resources
- Equipments impact each others’ failure, network of the equipment is a complex system
  > Graph of Equipment network and influence studies crucial
Thanks

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or

Iqbal + condition monitoring
MARKET VALIDATION PROGRAM (MVP)

SMART SMEs

Smart Sensors - Stage 2
Feasibility Study Report
The Smart Sense Platform

Smart Device Zone

Sensor Network Zone

Services/Apps Zone

Without AMI

With AMI

Distribution Business

Smart Sense Protocol

AMI Network with 3G - WiMAX - Other backhaul

AMI Sense Appliance

Hosted at each DB, maintained by Sensium

Smart Sense Protocol

SENSIUM

a DiUS company

Sensium Smart Sense Platform
The Smart Sense Platform

Value Proposition

• Provides a low-cost, reliable, hosted and managed network that acts as the bridge to enabling the Commercial and Societal Benefits of Wide Area Sensing.

• Enables Sensor Manufacturers and Sensor Application Providers to accelerate the development and time to market of sensors and devices that instantly plug in, register and communicate across a pervasive network.

• Enables the instrumentation and measurement of virtually any meaningful information, in a timely manner that realises significant societal benefits to all Victorians.
Site Level Wide Area Sensing @ MONASH
Site Level Wide Area Sensing
@ MONASH

• Hosted at the Department of Electrical and Computer Systems Engineering Labs in Monash University Clayton
• Study will gather appliance level consumption profiles correlated with ambient temperature, and air flow (NILM algorithms being developed as a PhD project)
• Data gathered will assist site managers with EREP reporting (EREP is an innovative regulatory program that helps Victorian businesses meet climate change and resource scarcity challenges)
• Standards based 900Mhz IPv6 mesh radio communications network (CoAP, 6LowPAN, 802.15.4, TinyOS)
Site Sense with Monash University

Site Area Sensing - High Density

Campus
Industry
Shopping Centres
Sports & Entertainment
Hospitals

Sensor Network Zone

Services/Apps Zone

1. Sensor Adapter
2. Sensor Network Router
3. Sensor Analysis Server
4. 3rd Party Applications

Water SMART SENSOR
SMART SENSOR
Electricity SMART SENSOR
Interior Temperature

Campus
Industry
Shopping Centres
Sports & Entertainment
Hospitals

3G
4G
For Further Information

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Acknowledgements

Masud Moshtaghi, Mahsa Salehi, Bharat Sundaram
Dr Sutharshan Rajasegarar, Dr Chenfeng Zhou, Dr Jeffrey Chan
A/Professor Shanika Karunasekera
Professor Marimuthu Palaniswami, Professor Rao Kotagiri
University of Melbourne, Australia

Professor James Bezdek
University of West Florida, USA
Dr Timothy Havens
Michigan State University, USA
A/Professor Shan Suthaharan
University of North Carolina, USA
Overview of Current Research

- **Trustworthy wireless sensor networks**
  - Detecting anomalies in sensors
  - Privacy and integrity in participatory networks

- **Modelling evolving networks**
  - Detecting unusual changes in networks

- **Large-scale event correlation**
  - Identifying the root-cause of an incident so operations centres are not overwhelmed by alarms

- **Securing distributed control systems**
  - Maintaining robust control in the presence of insider data pollution attacks
Protecting networked control systems

- Control setting
- Measured error
- System input
- System output
- Measured output

Diagram:
- Control setting
- Controller
- System
- Sensors
- Measured output
Wireless Sensor Networks

- Wireless nodes for remote monitoring and control
- Self-configuring multi-hop network
- Limited
  - Power (Battery)
  - Bandwidth
  - Memory
  - Computation capability
- Susceptible to data corruption
Filtering corrupted data in sensor networks

- **Local anomalies**
  - Detecting anomalies that occur with respect to data at a single node

- **Global anomalies**
  - Detecting nodes whose data is anomalous with respect to other nodes

- **Modelling complex events**
  - Detecting unusual events that span different time scales and spatial scales
Local Anomalies

Need to build a robust model of normal behaviour at a sensor node
Global Anomalies

Compare local models of normal behaviour to identify globally anomalous sensors
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Challenge:

develop scalable data mining algorithms that can discover significant changes in very large evolving networks
Monitoring evolving networks

Research questions:

*Can we summarise where and when different types of changes occur?*

*Can we detect unusual changes?*

*Can we identify the root-cause of the change?*
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Distributed faults routinely create alarm storms that appear in multiple monitoring systems simultaneously.

**Challenge:** How to coordinate alarm correlation across multiple monitoring systems in a scalable way?

**Aim:** Develop distributed alarm correlation for large numbers of monitors without creating centralised bottlenecks.
Scalable alarm correlation
- Evaluation

Comparison of distributed P2P correlation system
with a centralized alarm correlation system

Test platform: PlanetLab

Sample nodes:

(North America)
planet2.scs.stanford.edu
planetlab-1.cs.princeton.edu
planetlab2.win.trlabs.ca

(Europe)
planetlab-2.imperial.ac.uk
planetlab1.cs.unibo.it
planetlab1.inria.fr

(Asia)
planetlab-01.naist.jp
hust1.6planetlab.edu.cn
csu1.6planetlab.edu.cn
Centralised vs Distributed
Alarm Correlation Performance

Can achieve same accuracy with 10x to 1000x speed-up
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Denial-of-service on networked control systems

Secure control: can delays in System Input and Measured Output affect system stability?
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Remote Monitoring Solutions

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Summary

1. INTRODUCTION

2. REMOTE MONITORING & MOBILITY TREND

3. CASE STUDY

4. BENEFITS

5. QUESTIONS?
INTRODUCTION
Introduction – Remote Monitoring Solutions

The Remote Monitoring Solution is a web-enabled service that combines:

1. Condition monitoring tools for collecting data
2. An expert/analyst to analyse the data remotely and
3. A good internet access to communicate management of machine health for informed decision-making.

The Remote Monitoring Service is ideal:

1. For plants with limited trained resources in condition monitoring
2. For operations with sites located remotely from central facility
Remote Monitoring Solution

- The Remote Monitoring Solution provides an infrastructure to track, manage, support and deliver critical information through a range of communication possibilities to:
  - Any user;
  - Anywhere;
  - Any device;
  - Any time;
  - Using any Internet access.

- This solution allows businesses to extend their resources, systems and processes in real time, no matter where your employees are to make decisions.
2

REMOTE MONITORING & MOBILITY TREND
Mobility Trends

- In 2012 the number of smart mobile phones will outnumber the PCs by 4 times.
- The first Internet experience for young generation will happen on smart mobile devices.
- In the next 4 years:
  - 75% of the industries will apply Wireless solutions;
  - Mobility will be standard for all industrial applications;
- Cross network (3G/4G/Wifi) mobile devices will replace old PDAs.

(Source: IDC. International Data Corporation - Wireless & Mobile Solutions 2011 Survey.)
The use of “everything as a service”

- Budget restrictions, high labour costs and the global competition will be the key driver for embracing new technologies such as virtualization.

- Remote Monitoring Solution also enables suppliers to supply their condition monitoring solutions "as a service" (SaaS - Software as a Service) via the Internet, where customers access their applications and perform their activities without worrying about IT infrastructure, software updates, servers management and others.

(Source: IDC. *Latin America IT Spending Patterns: The Latin America Black Book: Top 10 Predictions*. IDC #LA19160, Volume 1, Janeiro 2009.)
Remote Monitoring Solution

On-line Data Acquisition

Off-line Data Acquisition

Data sent through Internet 3G, 4G, WiFi, Satellite, etc

CMMS SDCD DCS Reports Reliability Diagnostic

3rd Parties (Ex.: Oil Analysis Lab.)
Remote Monitoring Centre
3

Case Study
Case 1: Remote Monitoring - Dragline (Hoist Box HSS NDE - Bearing Fault)

Business Case:

Customer used to do periodic vibration analysis with limited success given the fact that conditions were not the same at the time of collecting vibration data.

In addition, the Dragline had to be stopped for couple of hours to acquire the vibration data on scheduled basis.

Customer therefore was looking for an advanced and efficient way of monitoring their draglines giving satisfactory result without scheduled production loss.
Case 1: Remote Monitoring - Dragline (Hoist Box HSS NDE - Bearing Fault)
Case 1: Remote Monitoring – Dragline (Hoist Box HSS NDE - Bearing Fault)

Flow of data

A: On-line system
B: Switch
C: GPRS Router
D: Antenna

Mobile phone network

Internet

SKF Web Servers
Case 1: Remote Monitoring - Dragline (Hoist Box HSS NDE - Bearing Fault)

- On-line data acquisition device with “order tracking” and active range window based on speed and direction to monitor the Drag and Hoist mechanism.

- Automated diagnose sent through e-mail and SMS 24/7.
Case 1: Remote Monitoring - Dragline (Hoist Box HSS NDE - Bearing Fault)
Case 2: Remote Monitoring – Dragline (Hoist Box HSS NDE - Bearing Fault)

- Fault identified on very early stage.
- Plenty of time for maintenance team to schedule all resources to fix the problem before any breakdown.
- Provides crucial information to identify the root cause of the problem and actions to avoid or reduce the reappearance of similar faults.
Case 2: Remote Monitoring – Winder (Bearing Fault)

**Business case:** The main cage of the drum bearing had some problem and the customer wanted to keep the production on-going for the next six months.

The need was to monitor the degradation of the bearing for the next six months.

The winder was running at a variable speed (i.e., 0 to 50 rpm).

**Solution:** On-line data acquisition device with twelve vibration sensors and one tachometer speed sensor plus remote analysis.

Automated diagnose sent through e-mail and SMS 24/7.
Case 3: Remote Monitoring – Winder (Bearing Fault)
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Case 2: Remote Monitoring – Winder (Bearing Fault)
BENEFITS
Benefits – Remote Monitoring Solutions

- Significantly reduction on capital investment (CAPEX vs OPEX).
- Data security and availability.
- Knowledge capturing and sharing.
- Cross sites integration.
- Global network.
- 24/7 automated on-line diagnose information.
- Interface with other asset management systems such as CMSS or EAM.
- Sustainable solution.
- Reduce maintenance cost.
- Increase overall asset efficiency.
5 QUESTIONS?
Working with Monash University

Dr Robin Stanley
Senior Business Development Manager
Faculty of Information Technology

www.it.monash.edu
Monash is experienced in working with industry
Research that is affordable

- A variety of Commonwealth and State schemes:
  - ARC Linkage
  - Technology Voucher Program
  - Innovation Voucher Program
  - Digital Futures Fund

- Cash contributions are eligible for the R&D tax incentive:
  - research project costs supported at 90 cents in the dollar
Arrangements tailored to your needs

- Linkage
- POC
- Honours
- Consulting
IP issues are not an obstacle

- Our primary objective is to make an impact
  - through commercialisation with industry partners
  - revenue is always secondary
  - Monash licences are fair and flexible

- IP protection is applied where appropriate
  - annual patent expenditure ~$1M