On-Line Fault Detection in Wind Turbine Transmission System using Adaptive Filter and Robust Statistical Features

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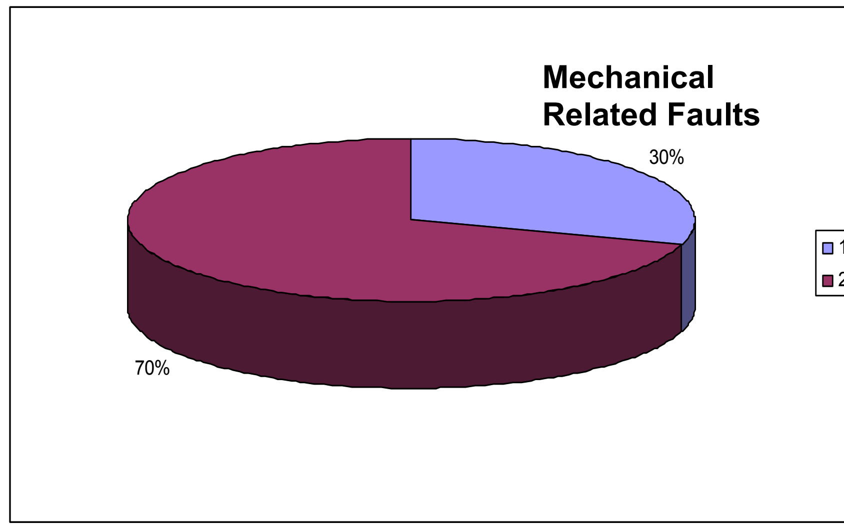
Outline

- Introduction
- Theoretical Basis
- Data Collection
- Analysis Results
- Conclusion

Introduction

- Wind Power is the world's fastest growing renewable energy source.
- Reducing the cost of generating the wind energy becomes a critical issue.



[1] Ribrant, J., and Bertling, L.M., "Survey of Failures in Wind Power Systems With Focus on Swedish Wind Power Plants During 1997–2005," *Energy Conversion, IEEE Transactions on* , vol.22, no.1, pp. 167,173, 2007

Introduction…

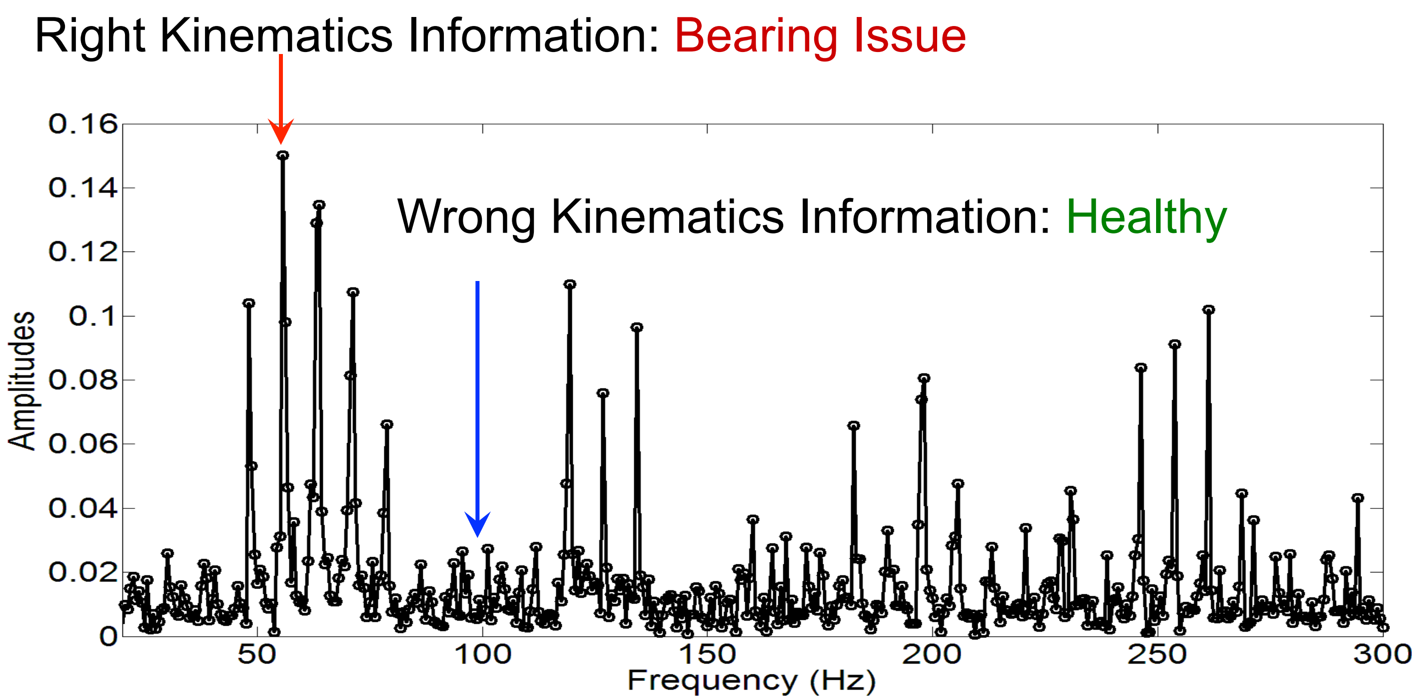
- Online condition monitoring of the wind turbine mechanical transmission system provides the following benefits:
  - Greatly reduce the maintenance cost,
  - Avoid catastrophic failure,
  - Improve the reliability of the whole system.

Introduction…

- Challenges:
  - Uncertain kinematics information
  - Speed and loading variations
  - Low fault signal-to-noise ratio
  - Large volume of signal with different types

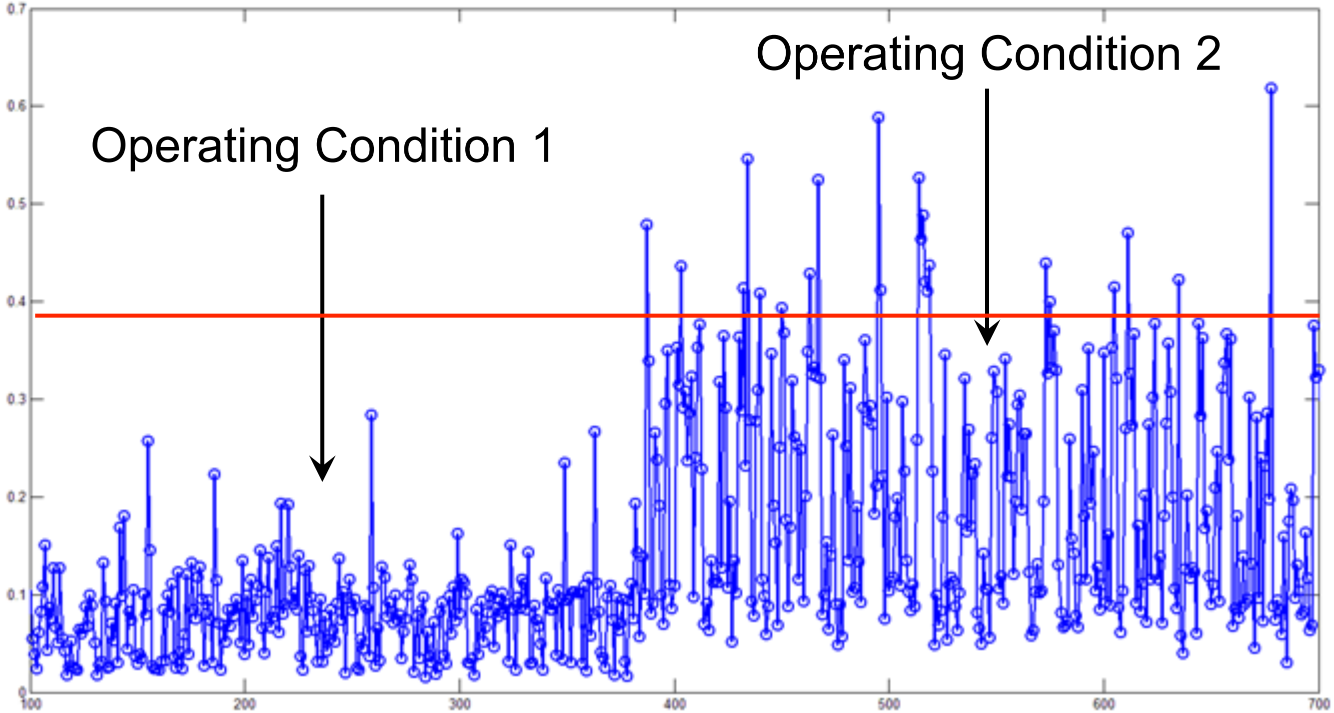
Introduction…

- Uncertain kinematics information



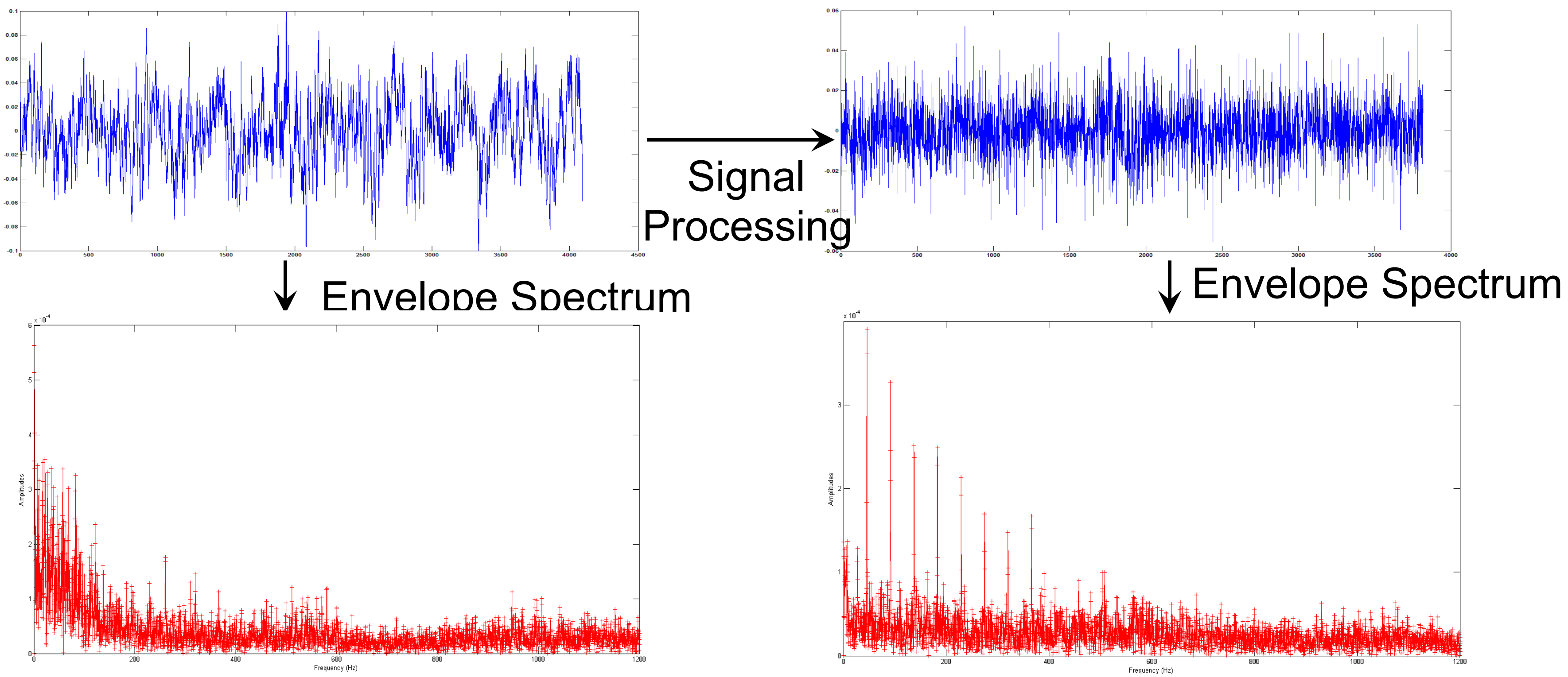
Introduction…

- Speed and loading variations



Introduction…

- Low fault signal-to-noise ratio



Introduction…

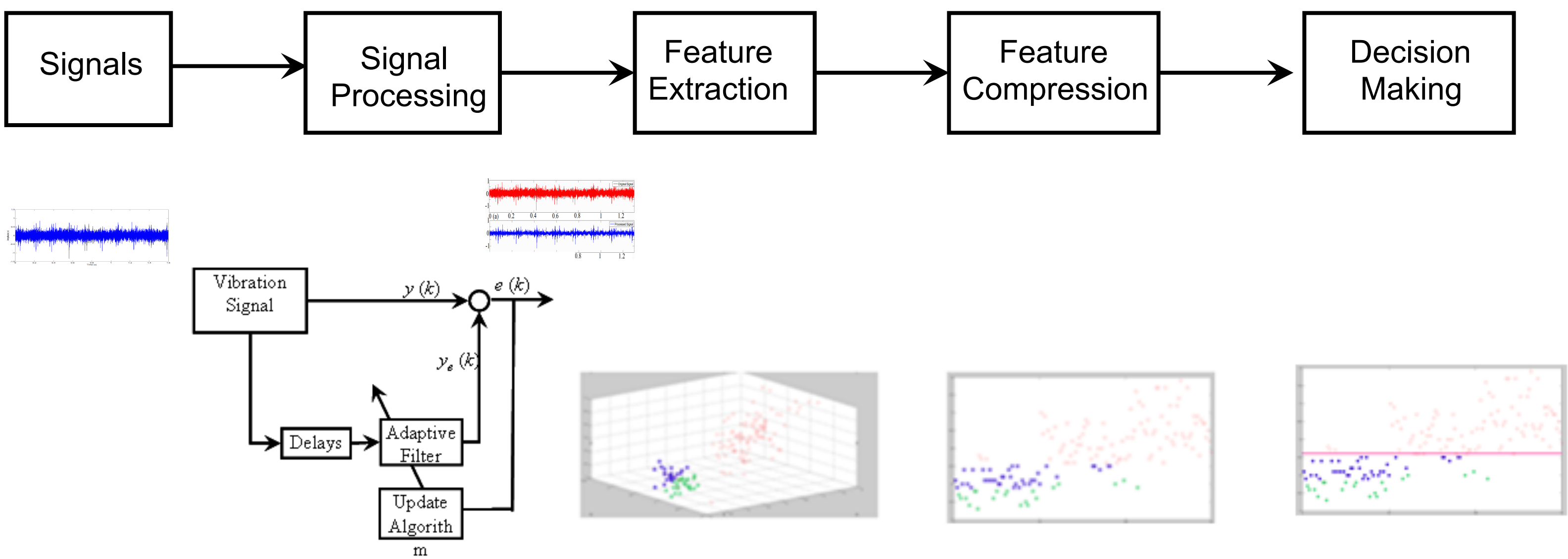
- Large volume of signal with different types
  - When gating condition met the requirements, a wind farm with size of 1000 wind turbines,
    - 72000 to 230400 extracted trend values daily
    - 24000 to 96000 time waveforms and spectrums daily

Introduction…

- In real applications, effective fault detection algorithms are an essential part of the condition monitoring system, especially for the online continuous monitoring systems, like wind turbine condition monitoring systems.

Theoretical Basis

Schema of the Proposed Methodology



Self-adaptive noise cancellation

Statistical Features

Linear Discriminate Analysis

Bayesian Analysis

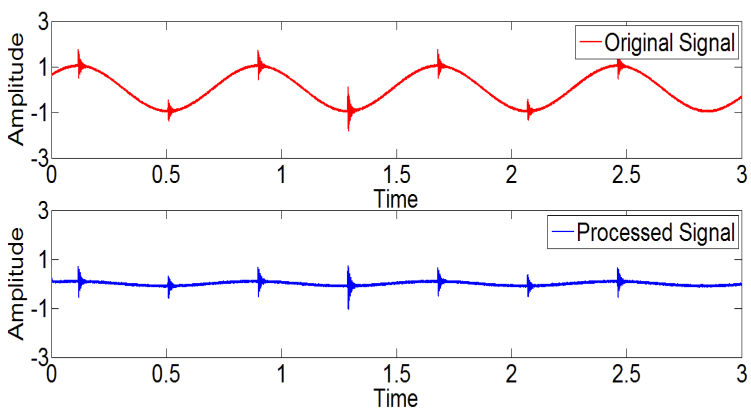
Theoretical Basis…

Signal Processing

Simulation Example

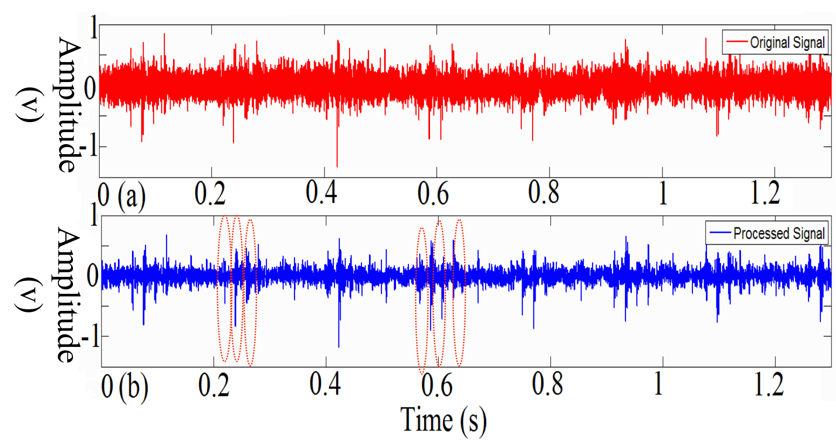
$$y_1 = \sin(w * pi * t)$$

$$y_2 = A_t * e^{-N*t} * \sin(w_1 * pi * t)$$



Real Vibration Signals

Vibration signal with bearing inner race defect



Theoretical Basis…

Extracted Features

- Kurtosis

$$x_{KT} = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^4}{\left(\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2\right)^2}$$

- Crest Factor

$$x_{CR} = \frac{\max|x_i|}{\sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2}}$$

- RMS

$$x_{rms} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2}$$

- Impulse Factor

$$x_{IF} = \frac{\max|x_i|}{\frac{1}{n}\sum_{i=1}^{n}|x_i|}$$

- Skewness

$$x_{KT} = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^3}{\left(\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2}\right)^3}$$

Linear Discriminant

$$s = [s_1, s_2, \ldots, s_n]$$

$$y = w^T s$$

→ One dimensional feature

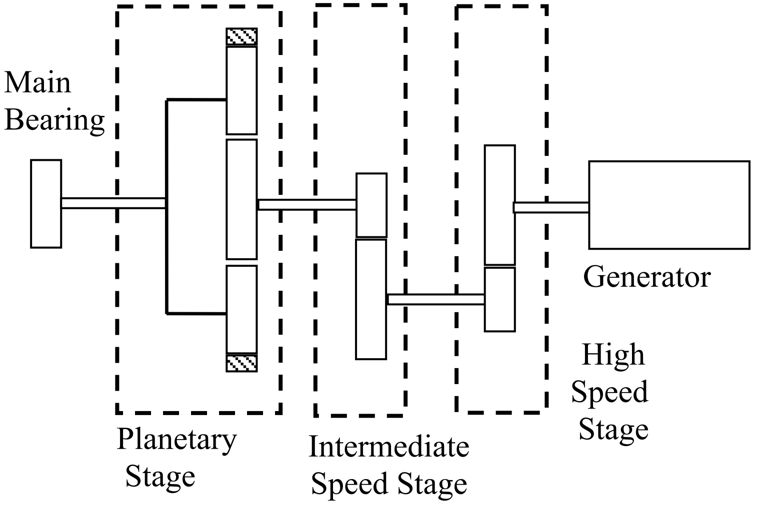
$$y = [y_1, y_2, \ldots, y_n]$$

$$J(w) = \frac{|\tilde{\mu}_1 - \tilde{\mu}_2|^2}{\tilde{s}_1^2 + \tilde{s}_2^2}$$

$$w = S_W^{-1}(\mu_1 - \mu_2)$$

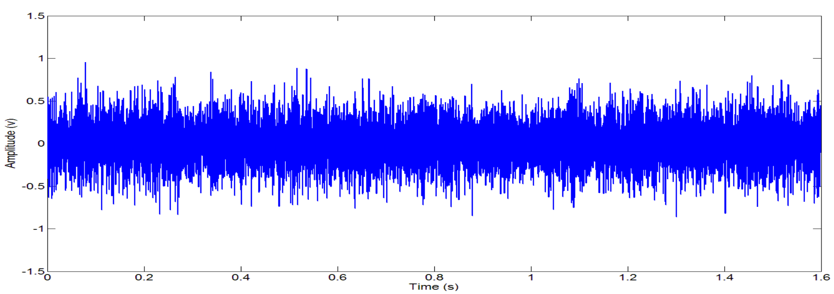
Data Collection

- SKF IMx-W
  - A robust measurement unit designed for installation in wind farms on and off-shore.
  - Sixteen analogue inputs and two digital inputs.
  - Simultaneous measurement of all channels.
  - Multi-parameter gating.

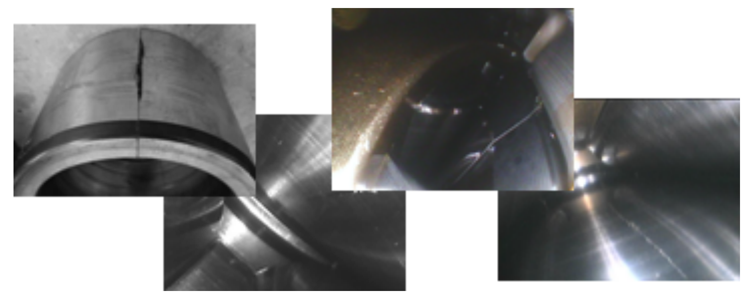


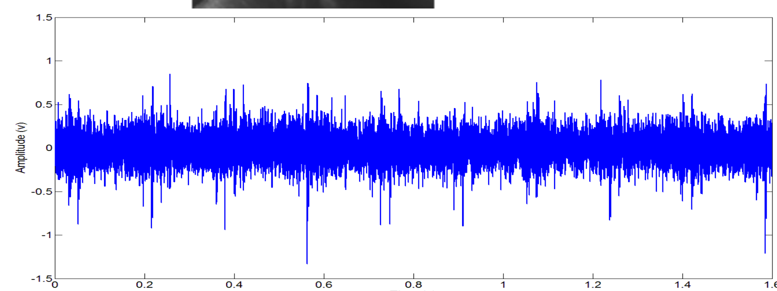
Data Collection…

- Recently, a number of SKF IMx-W, WinCon units were installed on a fleet of wind turbines to perform the online condition monitoring.



Vibration signal of the healthy gearbox





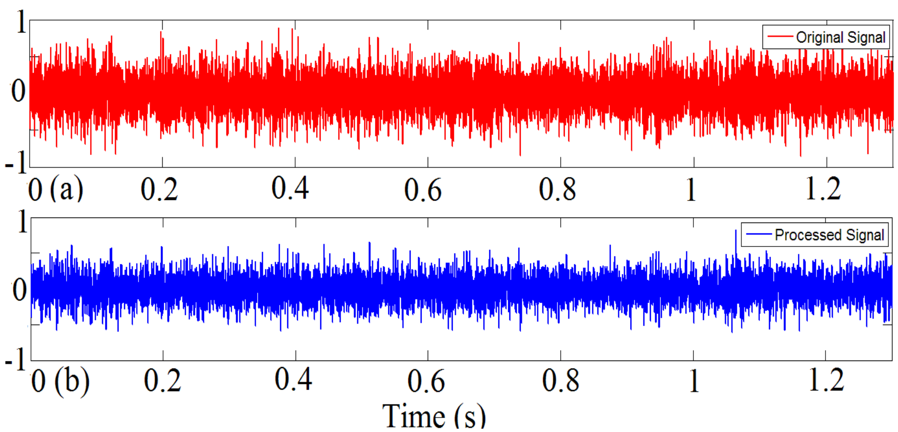
Signal of the gearbox with bearing inner race defect

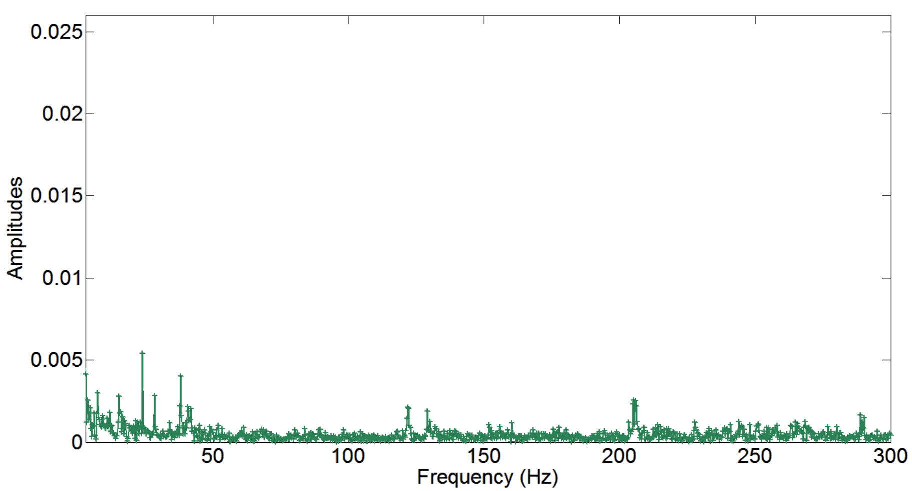
Data Collection…

- When gating conditions meet the settings:
  - Key features value: 10 Minutes
  - Time Waveform: 8 hours
  - Spectrum: 8 hours
- Sampling frequency: 5.12 kHz
- Sampling time length: 1.6 seconds

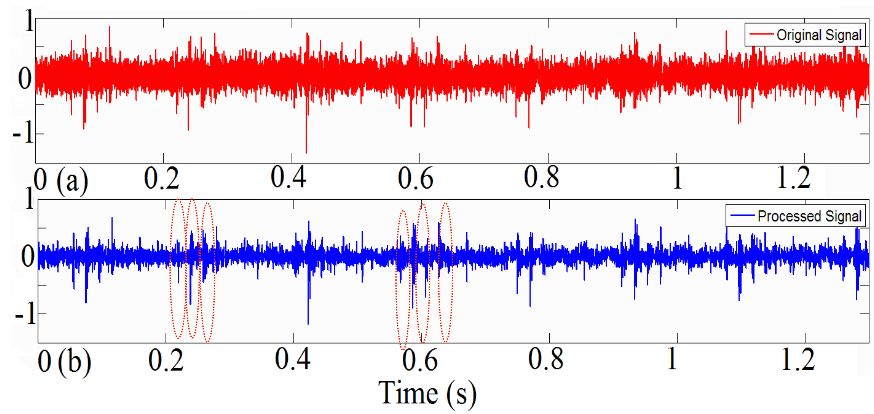
Analysis Results

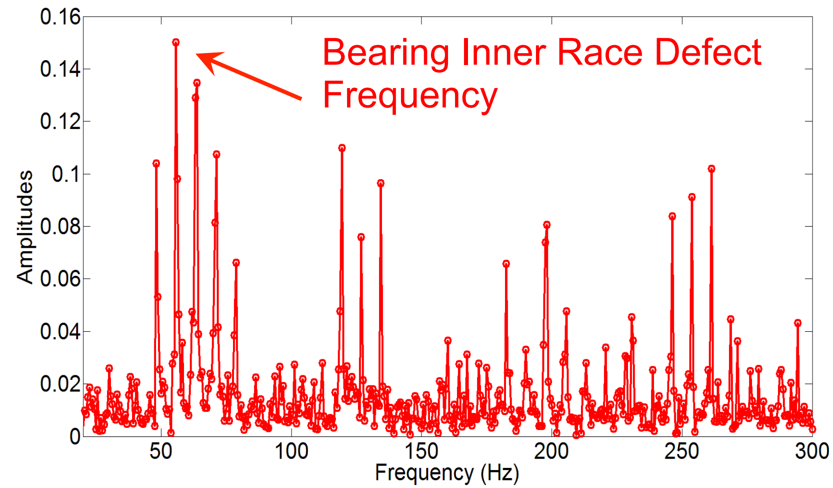
Vibration signal of the healthy wind turbine





Vibration signal of the damaged wind turbine





Analysis Results…

Table The calculated values of the processed signal of healthy gearbox and the gearbox with defect

Healthy Gearbox			Gearbox with Defect		
	Mean	**STD**		**Mean**	**STD**
Kurtosis	2.9413	0.2080	**Kurtosis**	6.7379	1.8137
Crest Factor	8.3849	1.7355	**Crest Factor**	12.8863	1.6221
RMS	2.0668	1.0749	**RMS**	1.6640	0.6494
Impulse Factor	10.5101	2.1233	**Impulse Factor**	17.6538	2.7323
Skewness	-0.0181	0.0892	**Skewness**	-0.0545	0.1636

Feature Compression

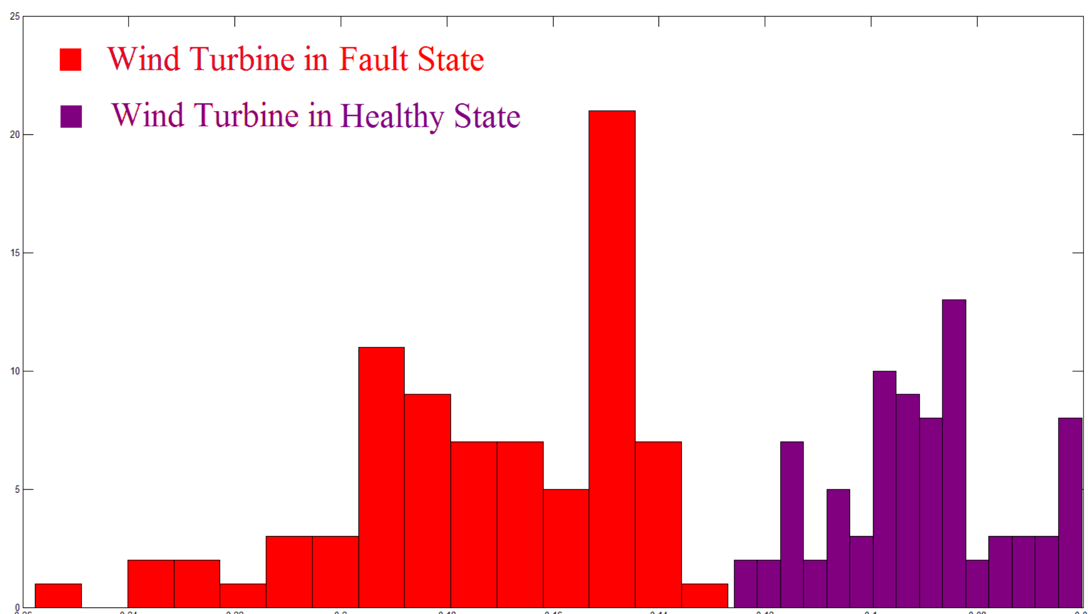


Figure The histogram of the transformed feature of the healthy machine and the machine with damaged components

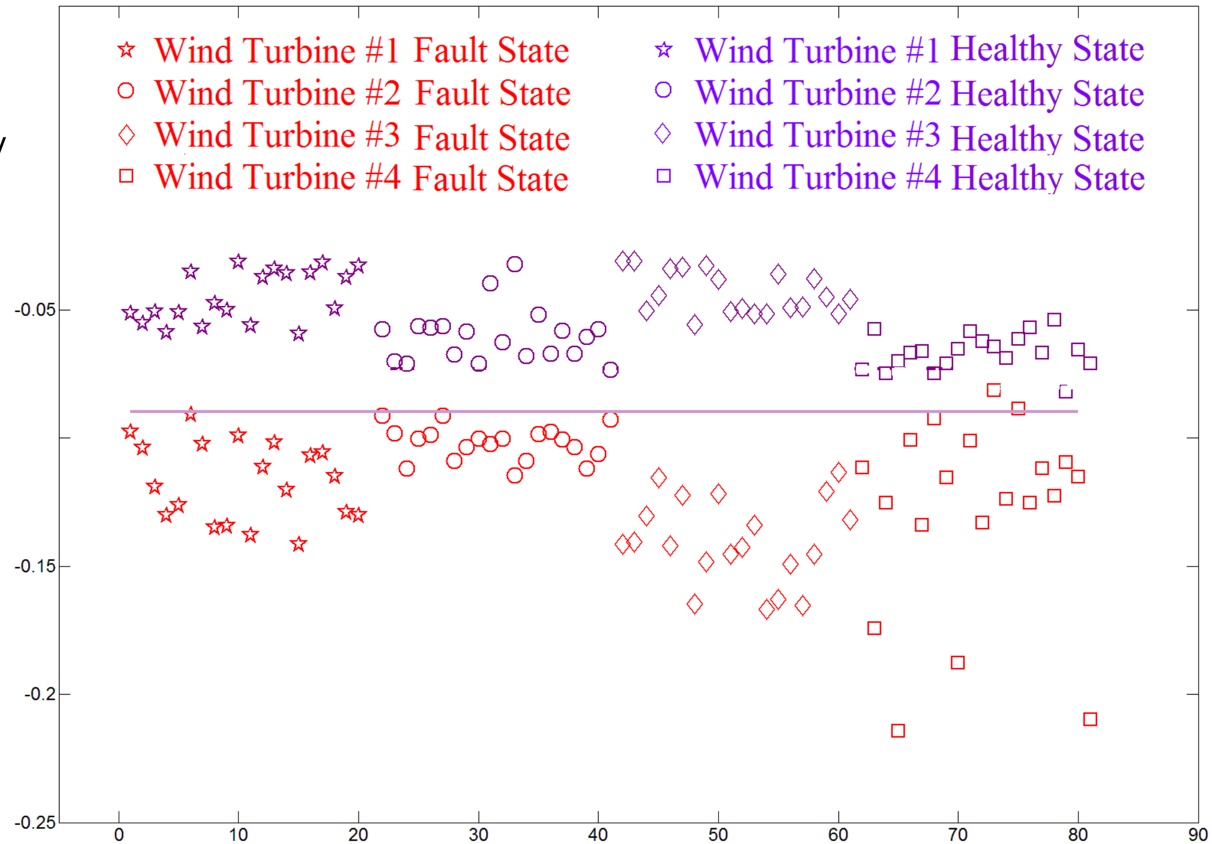
Analysis Results…

0.9 boundary:

•The system is deployed to a newly created wind farm

•The least fault sensitive boundary

• 98.750% fault detection accuracy

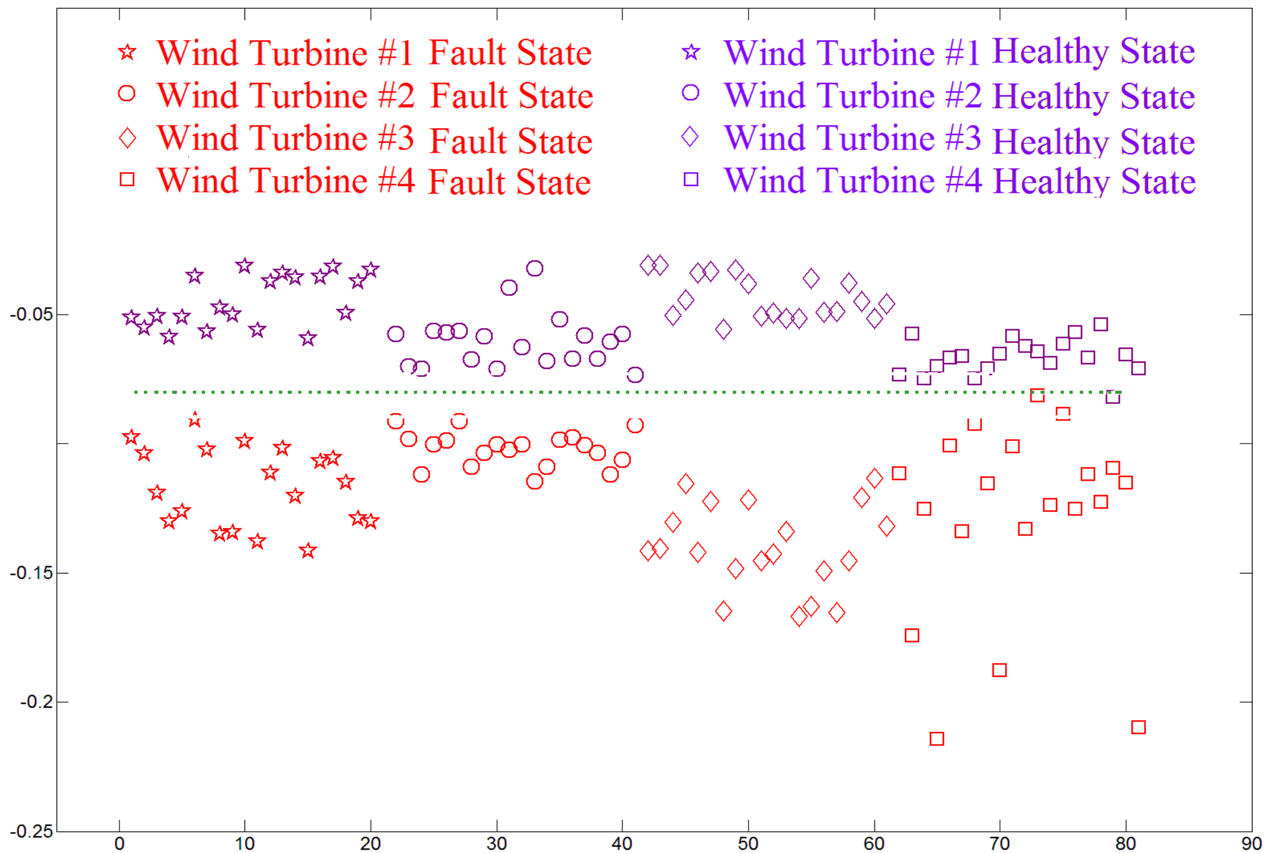


Analysis Results…

0.5 boundary:

•The moderate fault sensitive boundary

• 99.375% fault detection accuracy

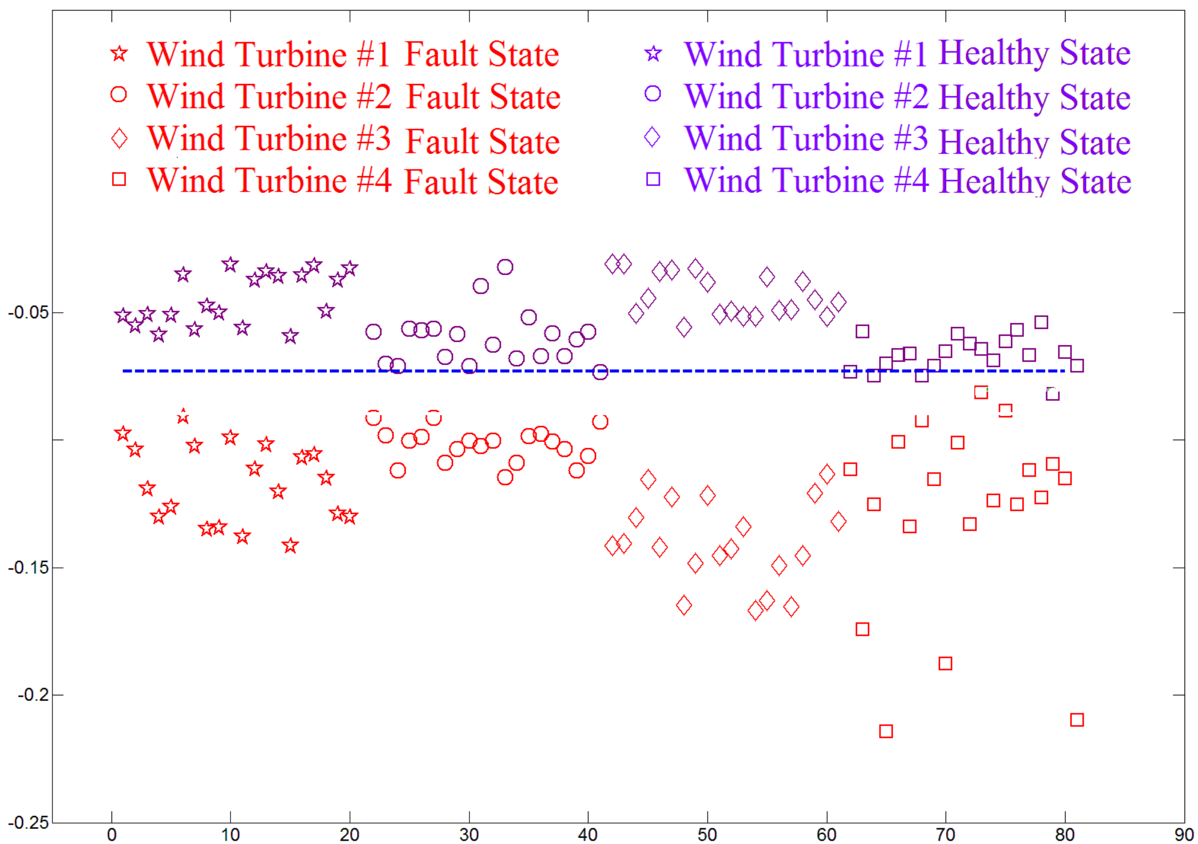


Analysis Results…

0.1 boundary:

•The most fault sensitive boundary

• 96.875% fault detection accuracy



Analysis Results…

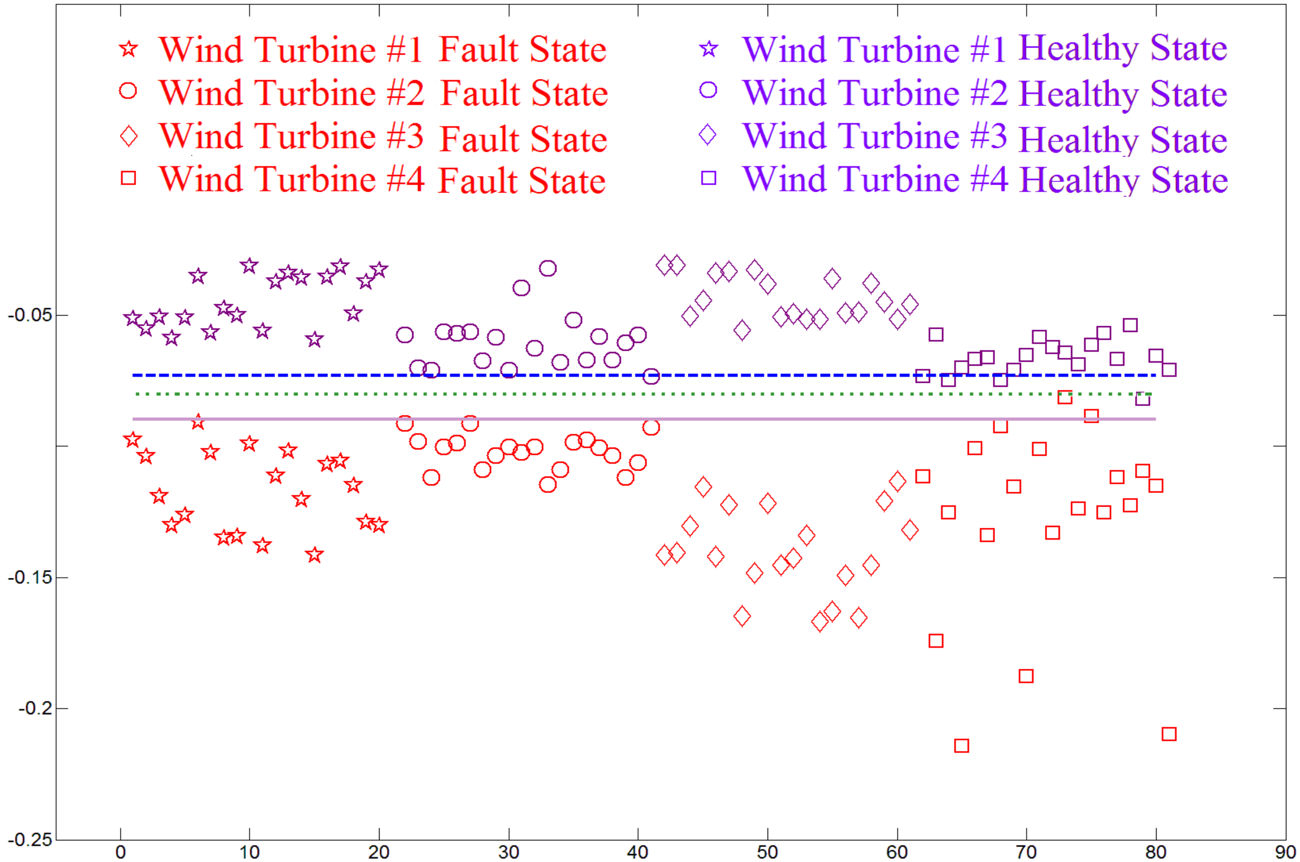
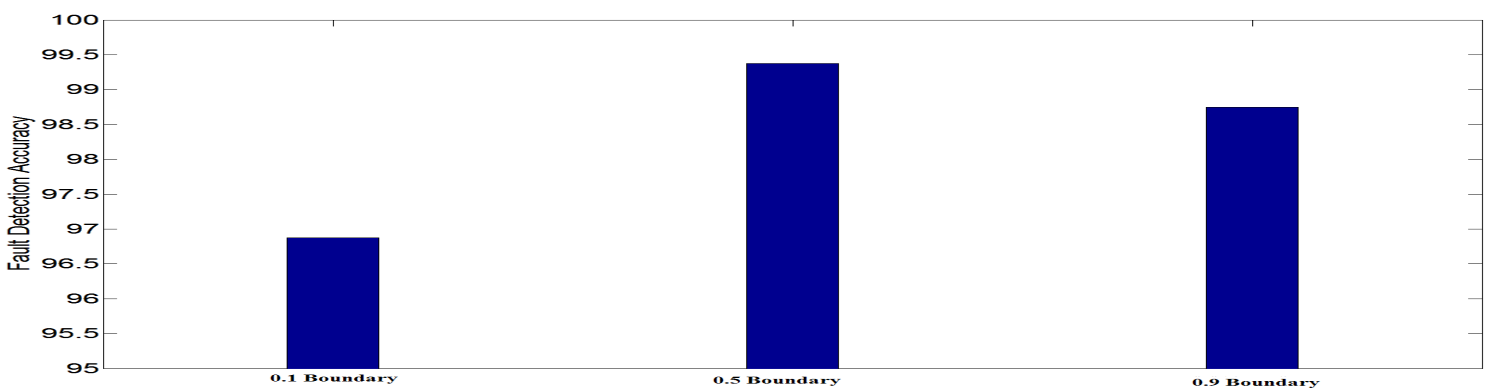


Figure. The transformed feature and the decision boundaries with different prior statistics (blue line: P(Healthy)=0.1, green line: P(Healthy)=0.5,pink line: P(Healthy)=0.9)

Analysis Results…

Table The confusion matrix of the different boundaries

		Calculated Healthy	Calculated Fault
0.1 Boundary	**True Healthy**	75	5
	True Fault	0	80
0.5 Boundary	**True Healthy**	80	0
	True Fault	1	79
0.9 Boundary	**True Healthy**	80	0
	True Fault	2	78



Conclusion

- An effective automatic fault detection methodology has been developed.
- The methodology consists:
  - Adaptive filtering technique to improve the fault SNR
  - LDA to reduce the features' dimensions.
- Wind turbine vibration signals obtained in real operation were used to demonstrate the effectiveness of the presented methodology.

Conclusion…

- In future work, it will be interesting to study the effectiveness of the developed method on a variety of rotating equipments in different industries and applications, such as ranging arms in the mining industries, pumps in the paper mill, and motors in the food industries, and so on.

Questions?