A New Acoustic Emission Sensor Based Gear Fault Detection Approach

Authors: Yongzhi Qu, University of Illinois at Chicago
Eric Bechhoefer, *GPMS LLC*
David He, University of Illinois at Chicago
Junda Zhu, NRG Systems

Presented by: Yongzhi Qu
University of Illinois at Chicago

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Outline

- Introduction
- Methodology
- Experiments setup
- Results and discussion
- Conclusions

Introduction

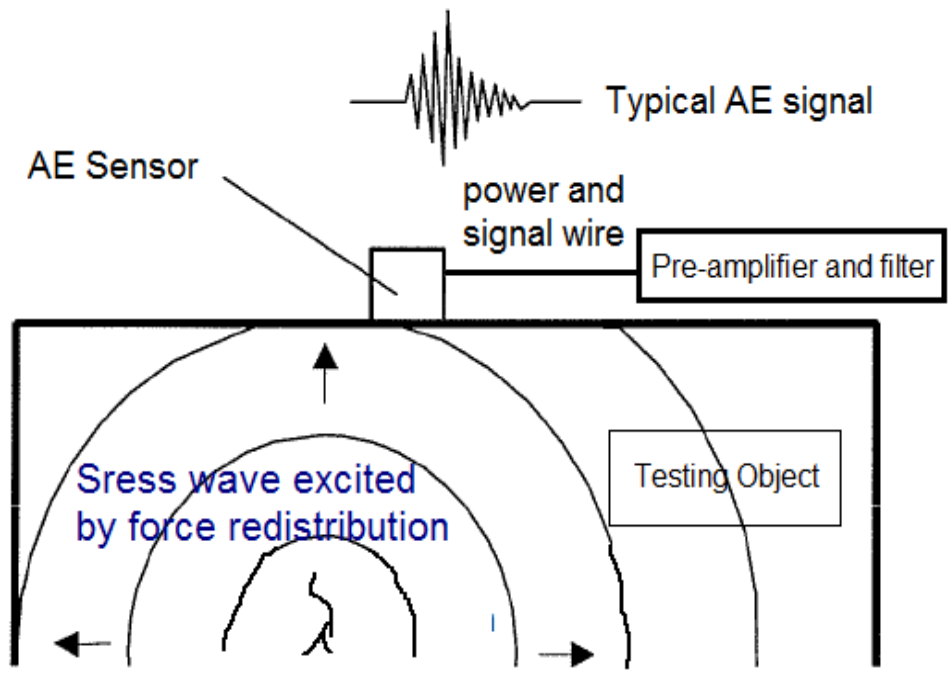
- Machinery fault diagnostic sensors

  - **Vibration Sensors: Accelerometers**
  - **Acoustic Emission sensors**
  - **Oil debris sensors**

- Vibration sensors are the most widely used, probability the most matured and effective techniques
- Acoustic emission shows high potential to initial fault detection and high sensitivity

Acoustic Emission

AE definition: Acoustic Emission (AE) is commonly defined as transient elastic waves within a material, caused by the release of localized stress energy.



Acoustic emission vs. Vibration

	Vibration	Acoustic Emission
Advantage	• Low cost • Easy to analysis	• Incipient fault • Sensitive to fault location • No resonance
Disadvantage	• Second derivative of the displacement • Structural resonance	• High sampling rate • Large storage and computational burden • Non-stationary

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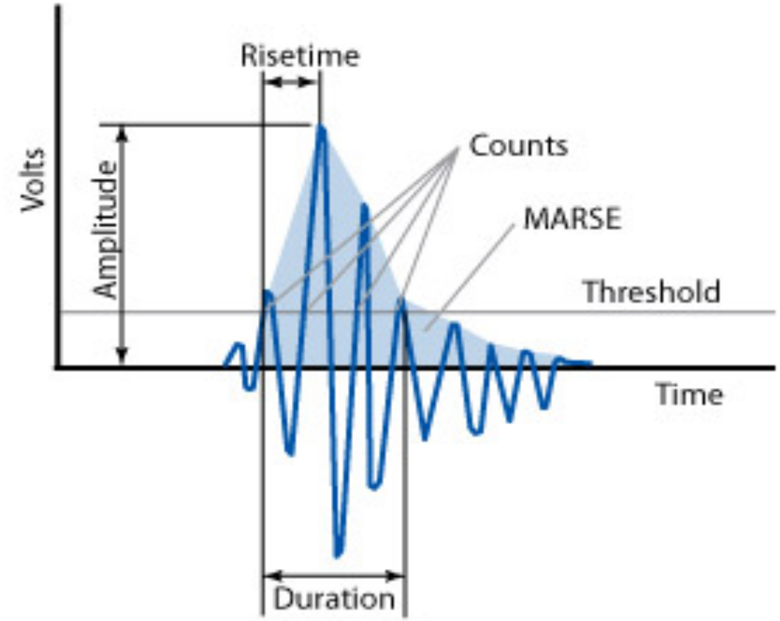
State of Art Methods

1. Burst type AE signals
2. Data driven methods
3. High data sampling rate

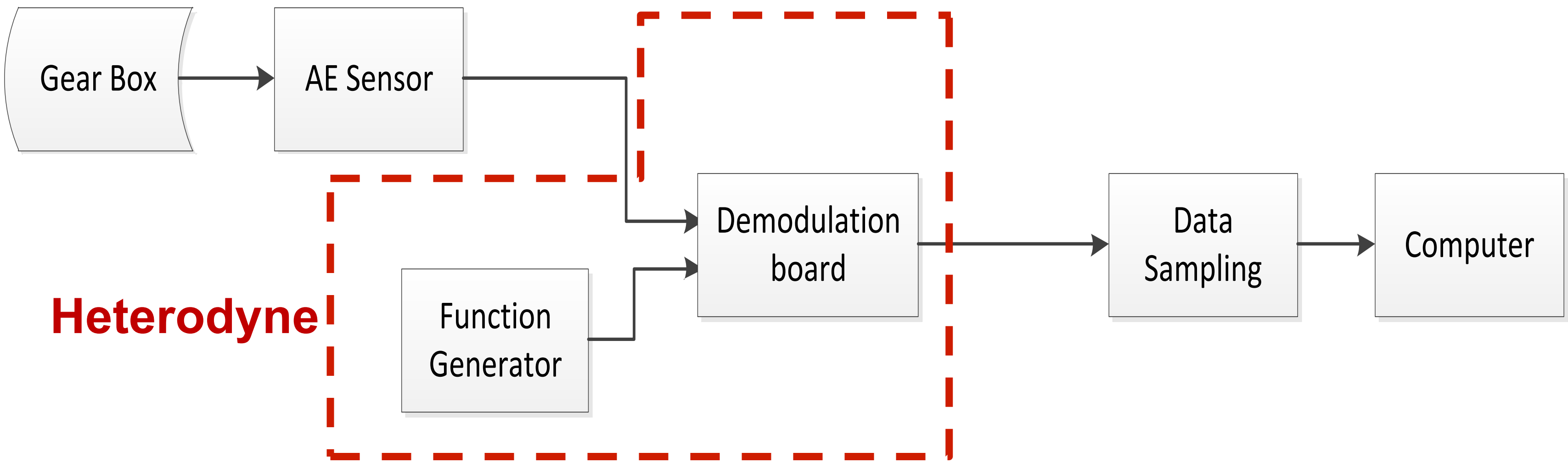


- Li and He (2012), introduced an EMD-based AE feature quantification method followed by Artificial Neural Networks (ANN) to do AE signal classification for fault detection.
- Pandya *et al*., (2013), developed a supervised learning methods for bearing fault detection using AE signals.

Challenge

- High data sampling rate
- Complicated signal processing methods
- Physical information missing
    - Bearing: Ball pass frequency
    - Gear: Meshing frequency and gear structure
- Long data training processing

Proposed AE processing methods



- Downshift AE signal frequency by heterodyning
- Collect AE signals with low sampling rate device
- Process AE signals like vibration

Heterodyne

- Heterodyne is a radio signal processing technique commonly used in telecommunication.
- Two signals at frequencies f_1 and f_2 are combined in mixer to get two new signals at the frequency $(f_1 - f_2)$ and $(f_1 + f_2)$
- Basic principle:

$$sin(\theta)\sin(\varphi) = 1/2\ cos(\theta - \varphi) - 1/2\ cos(\theta + \varphi) \qquad (1)$$

Spectral Kurtosis

- The SK of a signal $x(t)$ is defined as the energy-normalized fourth-order spectral cumulant as:

$$K_x(f) = S_{4x}(x) / S_{2x}^{2}(f) - 2$$

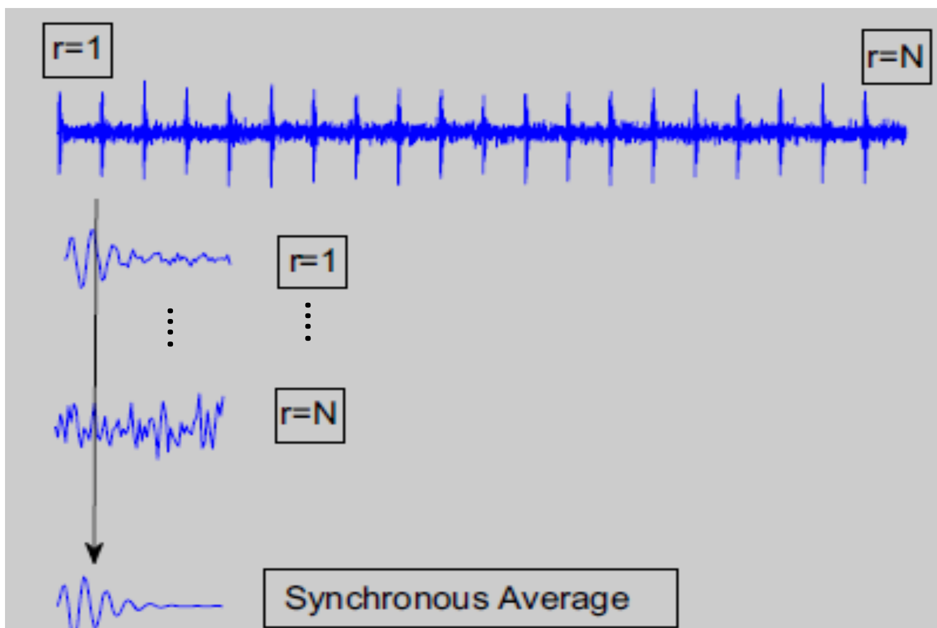
where $S_{nx}(f) = \langle |X(t,f)|^{n} \rangle$, $\langle \cdot \rangle$ stands for the time averaging operator, $X(t,f)$ is the complex envelop of signal $x(t)$.

- Kurtogram was proposed by Antoni and Randall (2006) to optimized the kurtosis

Time Synchronous Average

For a function *x*(*t*), digitized at a sampling interval *nT*, resulting in samples *x*(*nT*). Denote the averaged period by *mT*, Number of periods by *N* , TSA is given as (Braun, 1975):

$$y(nT) = \frac{1}{N} \sum_{r=0}^{N-1} x(nT - rmT) \qquad (2)$$



Derivative signal from TSA

- **Residual signal**: defined as a synchronous averaged signal with the shaft, mesh and their harmonic frequencies removed
- **Amplitude and phase modulation signal:** Obtained by Hilbert transform.
- **Teager's energy operator** (Teager *et al*., 1992)

$$\psi[x_i] = x_i^2 - x_{i-1} \cdot x_{i+1}$$

where $\psi[x_i]$ is the ith element in EO, x_i is the i^{th} element of x.

Gear Condition Indicators (CIs)

- **RMS:** $x_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i^2)}$
- **P2P**:Peak-to-peak amplitude
- **Crest factor :** the ratio of the peak and RMS

$$CF = |x|_{peak} / x_{rms}$$

- **Kurtosis**: the fourth order statistics of a signal, defined as:

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

Gear Condition Indicators (CIs)

FM4: The FM4 parameter is simply the kurtosis of the difference signal.

$$FM4 = \frac{N\sum_{i=1}^{N}(d_i - \bar{d})^4}{(\sum_{i=1}^{N}(d_i - \bar{d})^2)^2}$$

where di is the *i*-th element of the difference signal, *N* is the length of difference signal.

NA4: NA4 is an improved version of FM4. NA4 keeps the sidebands information.

$$NA4 = \frac{N\sum_{i=1}^{N}(r_i - \bar{r})^4}{(\frac{1}{M}\sum_{j=1}^{M}\sum_{i=1}^{N}(r_{ij} - \bar{r}_j)^2)^2}$$

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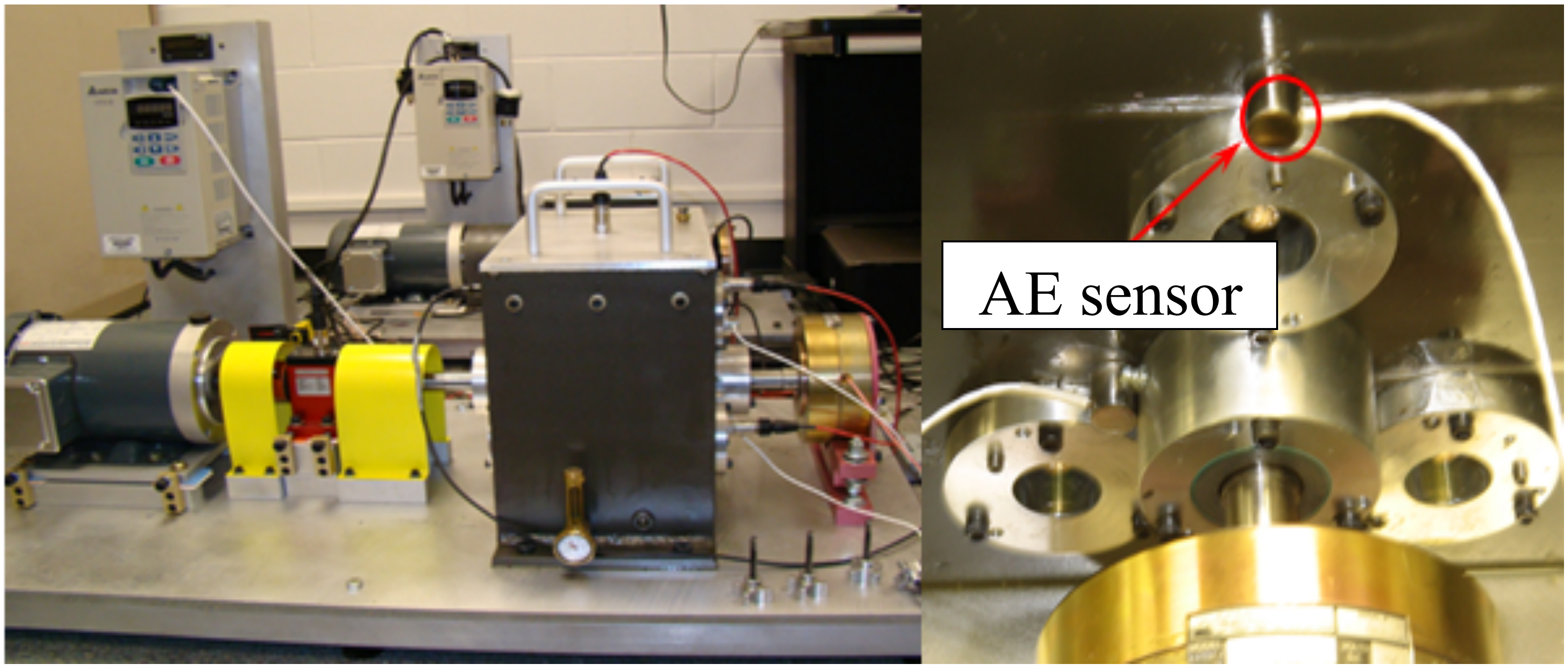
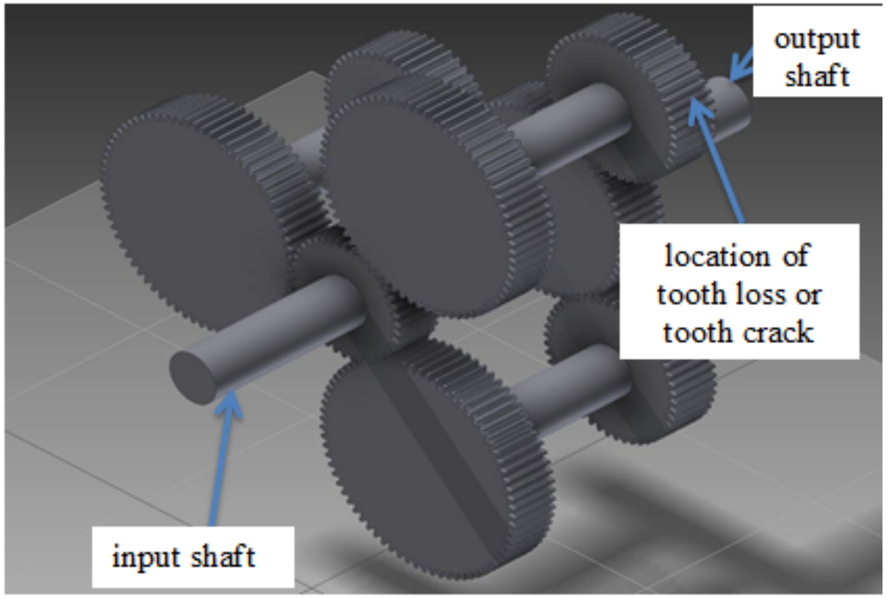
Test rig



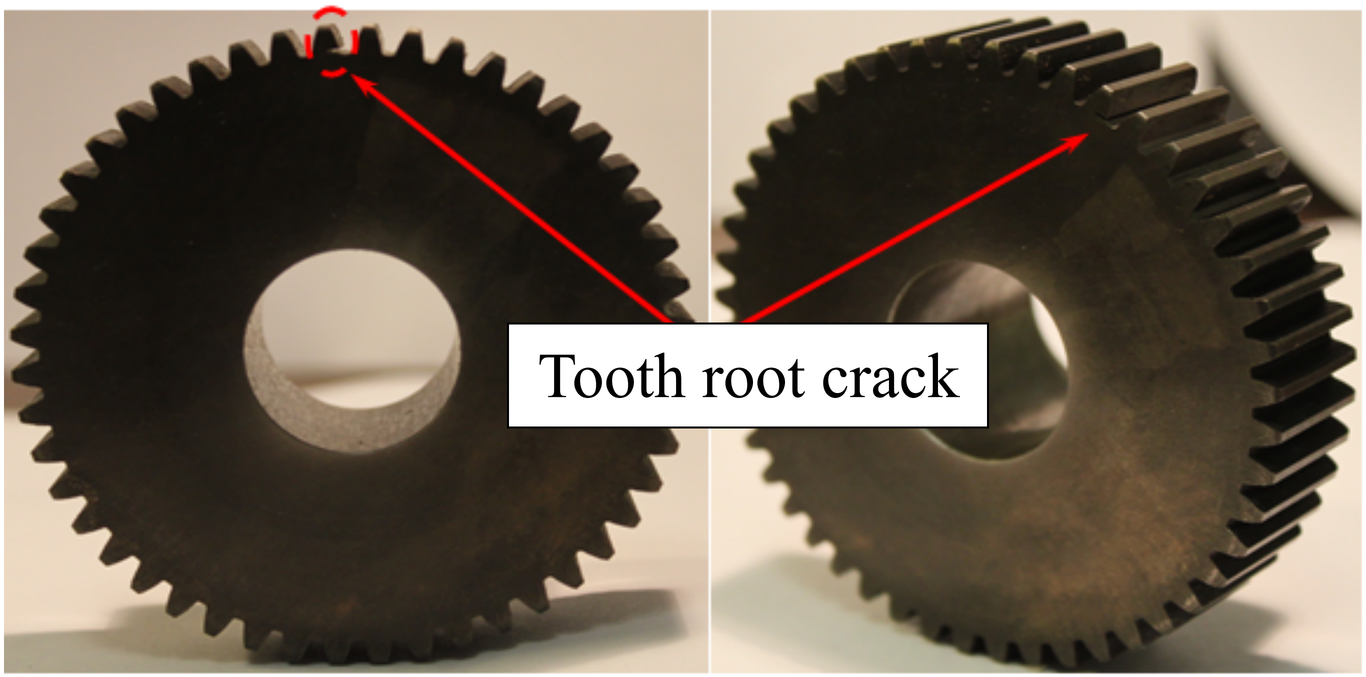
Test rig: Designed by SpectraQuest
AE sensors: Physical Acoustic corporation

Seeded Fault

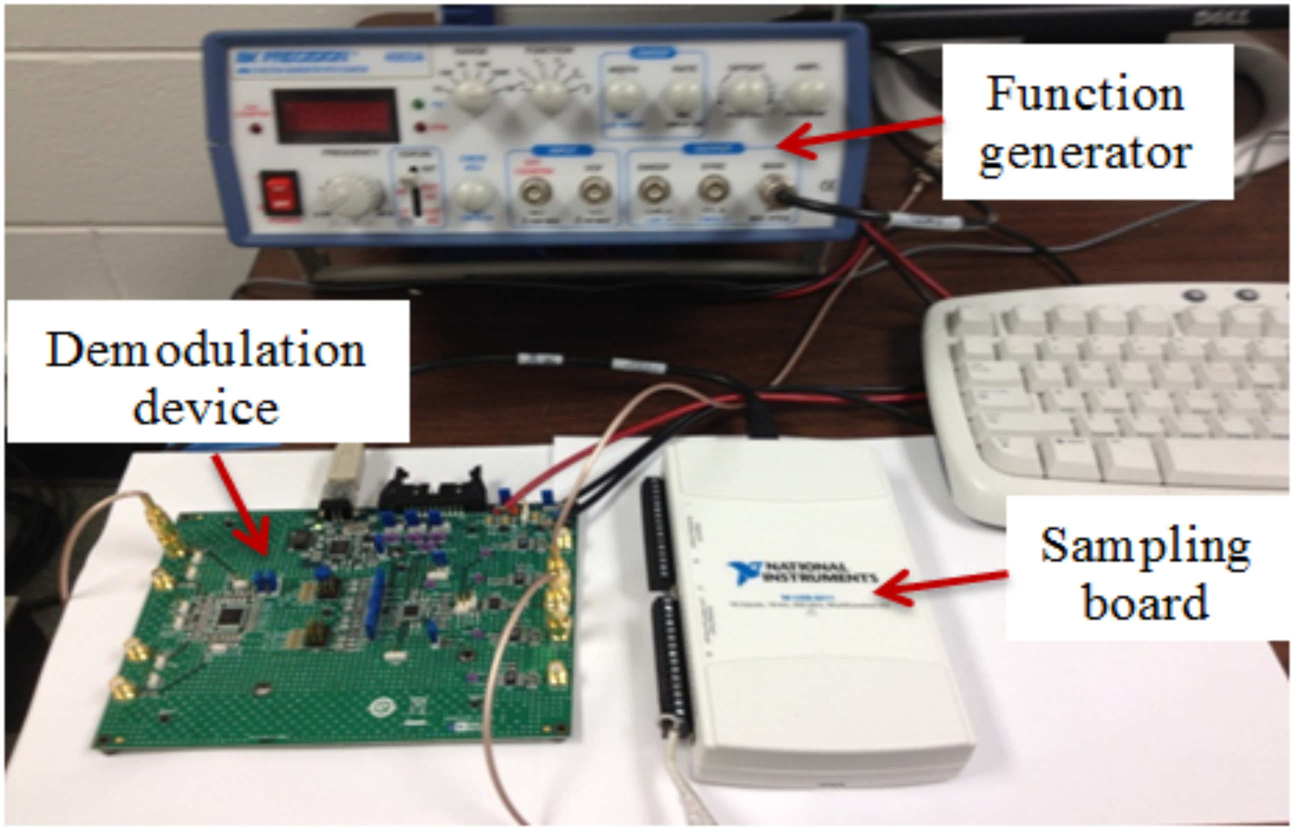


In the faulty gearbox, one of the intermediate gears with 48 teeth was damaged by cutting the root of a gear tooth with a depth equal to half width of the gear tooth by EDM (electric discharge machining) with a wire of 0.5 mm diameter, to simulate the root crack damage in real applications.

Seeded Faults



Data Acquisition Systems



Testing Conditions

- Multiple input speeds were tested, 10-60Hz

Input shaft speed (Hz)	10	20	30	40	50	60
Faulty gear shaft frequency	5.56	11.1	16.7	22.2	27.8	33.3
Output shaft speed	4.17	8.33	12.5	16.7	20.8	25

- 0 loading condition are tested

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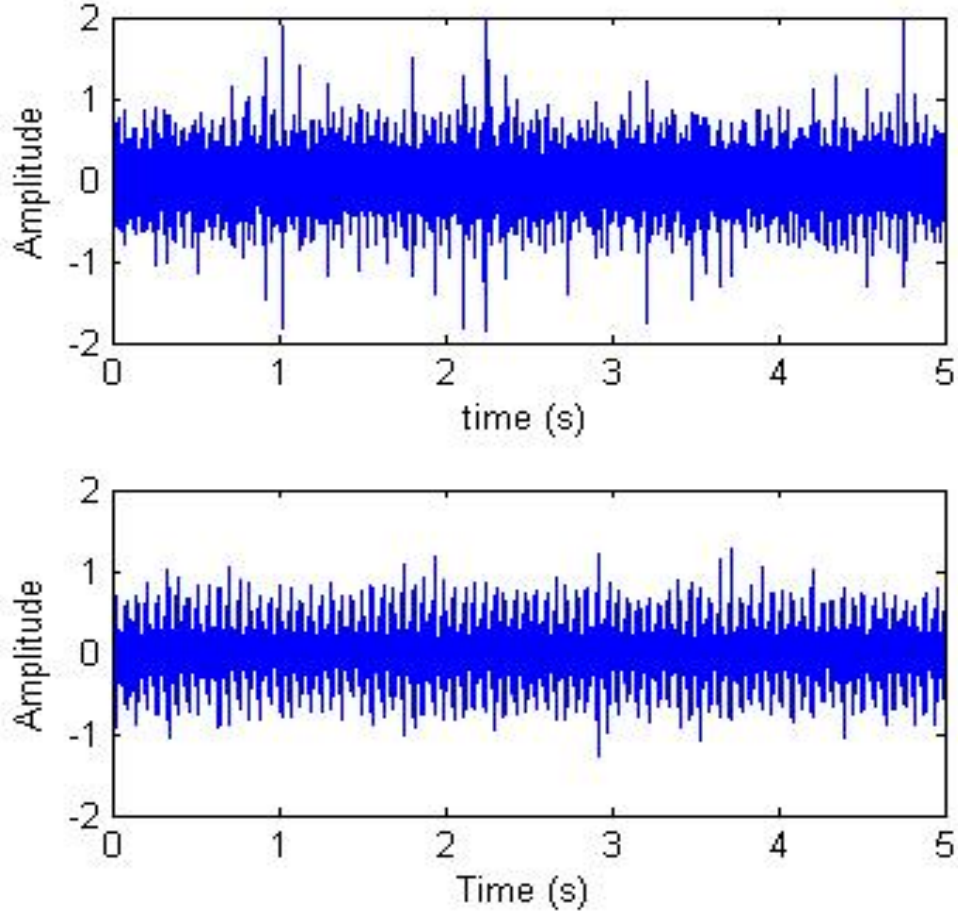
Raw data

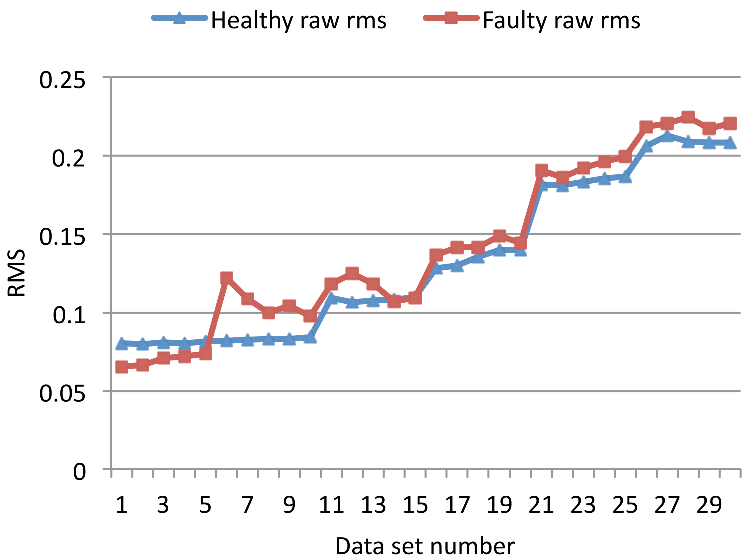


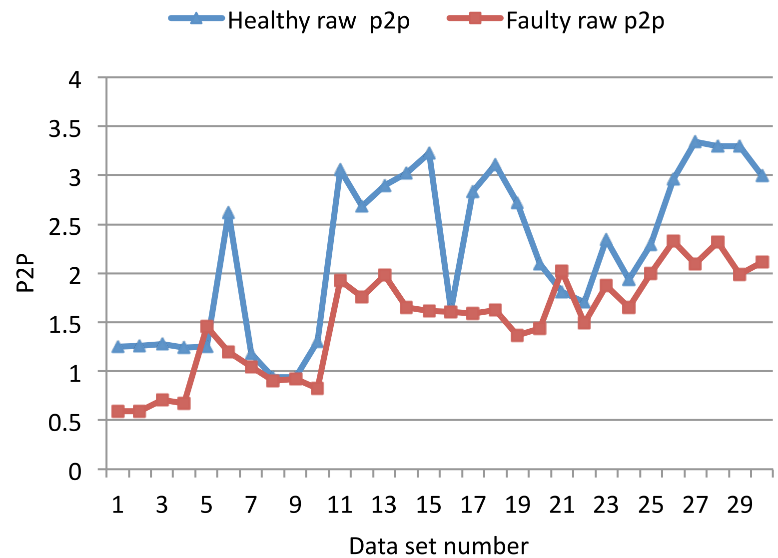
Healthy

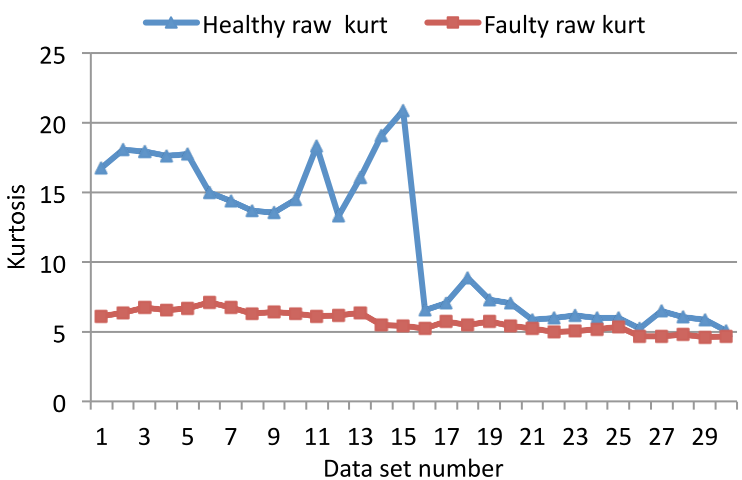
Faulty

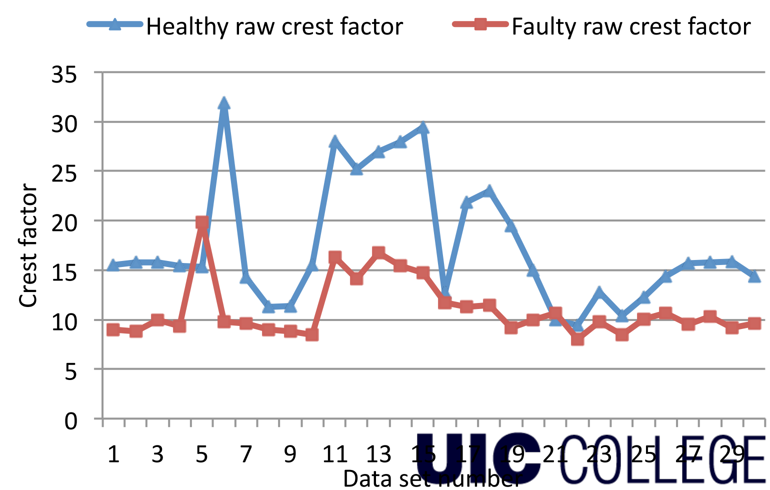
Healthy (upper) and faulty AE signals (lower)

Raw data analysis

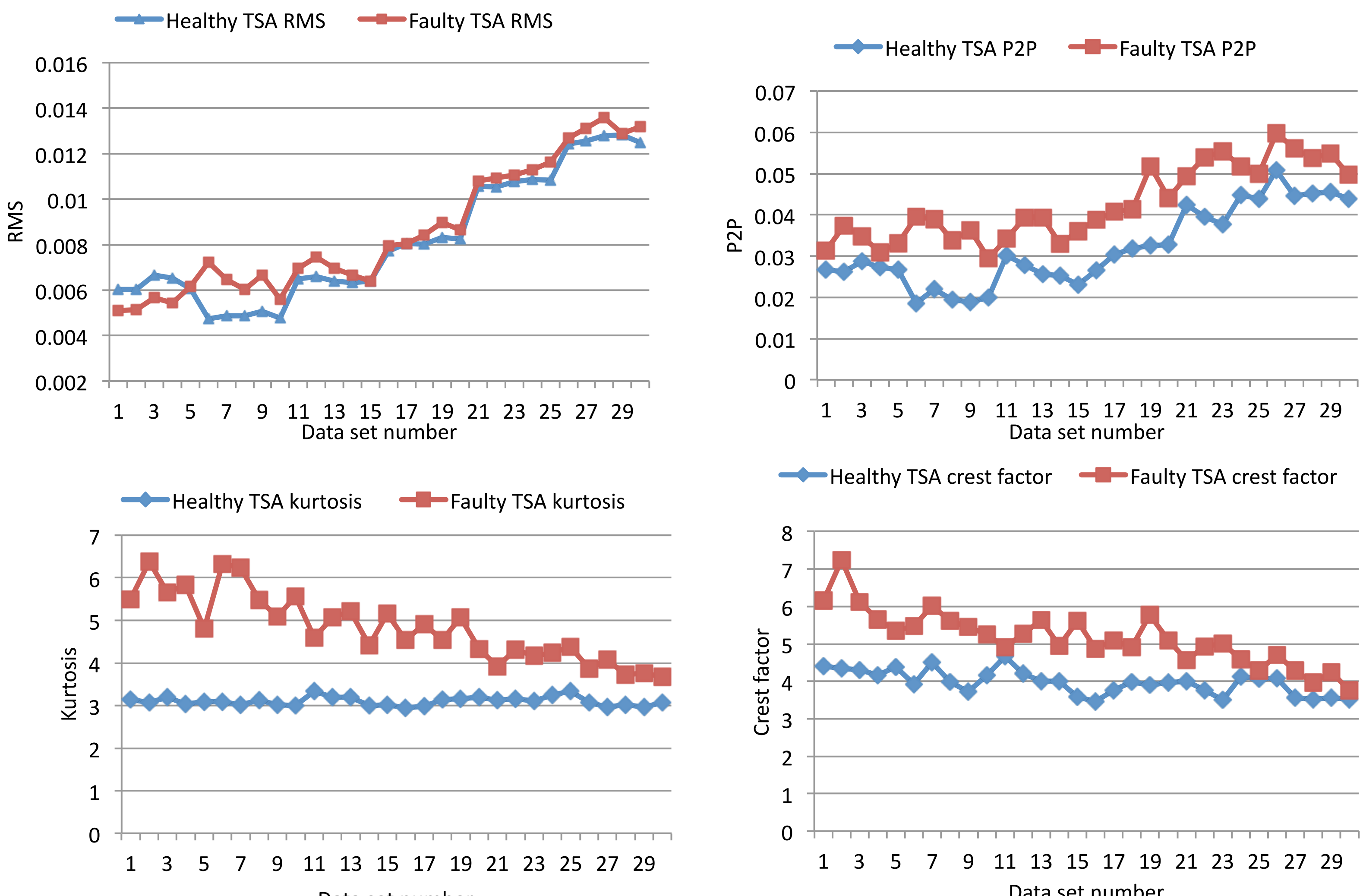








Results of Proposed Methods



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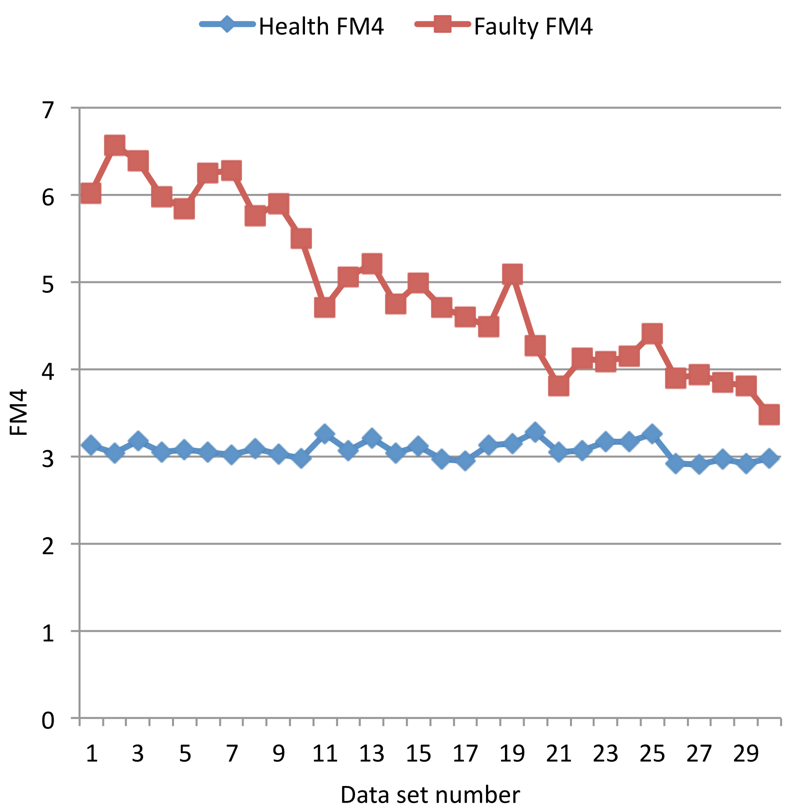
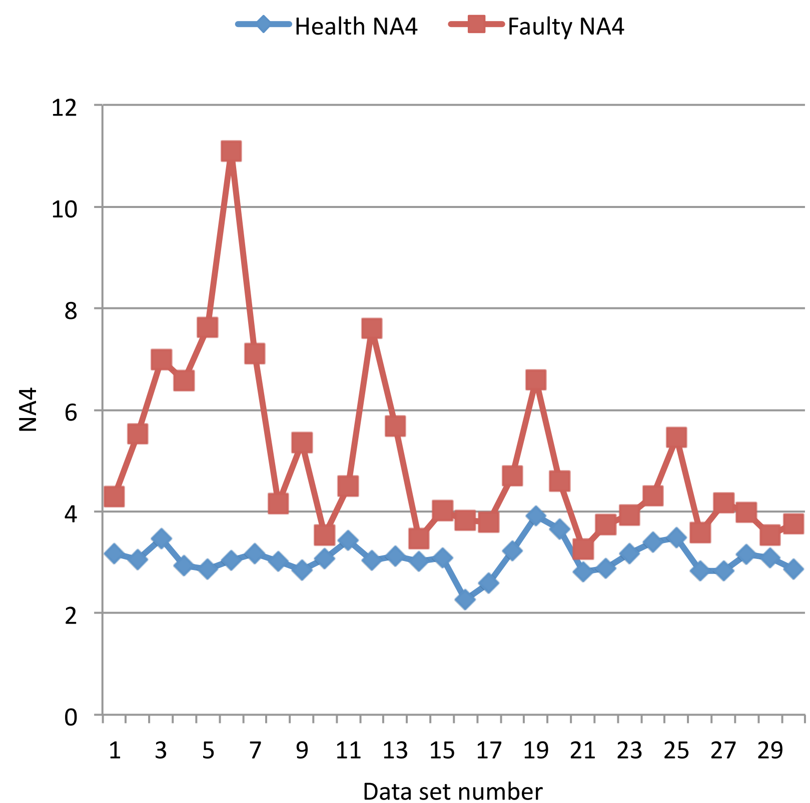
Results (cont.d)





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Conclusions

- Heterodyne can effectively shift the frequency of AE signals down
- Using Spectral kurtosis and TSA can largely enhance the fault feature
- Kurtosis based CIs works well for tooth crack fault

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Thank you

Questions?