PENNSTATE ARL

PSU Center of Excellence in Structural Health Management

Diagnostics and Prognostics for System Health

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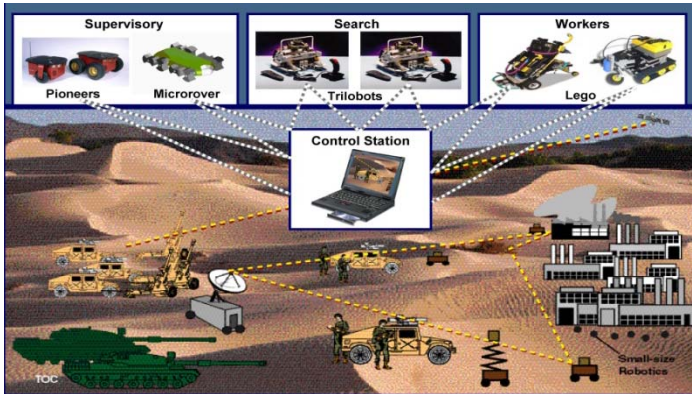
Overview

- Introduction to ARL
- System Engineering and Architectures
- Diagnostic and Prognostic Processing
- Structural Monitoring Examples
- Closing Thoughts

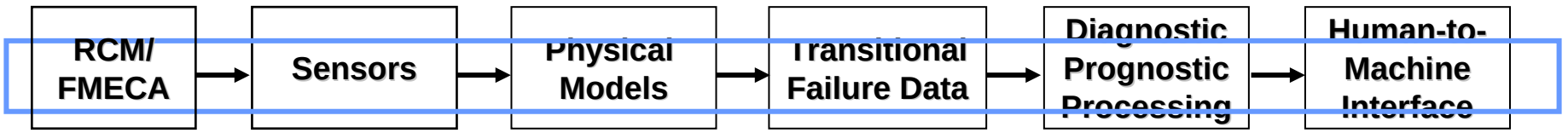
ARL - University Affiliated Research Center



- Chartered by the US Navy to serve as a trusted agent of the government and to provide a laboratory base for science and technology
- 1000+ PSU faculty and Staff
- Partner with Government, Universities and Industry
- Work from TRL 1 to TRL8-9
- Core competencies:
  - Acoustics
  - Guidance and control
  - Thermal energy systems
  - Hydrodynamics, hydroacoustics, and propulsor design
  - Materials and manufacturing
  - Navigation and GPS
  - Communications and information
  - Graduate education

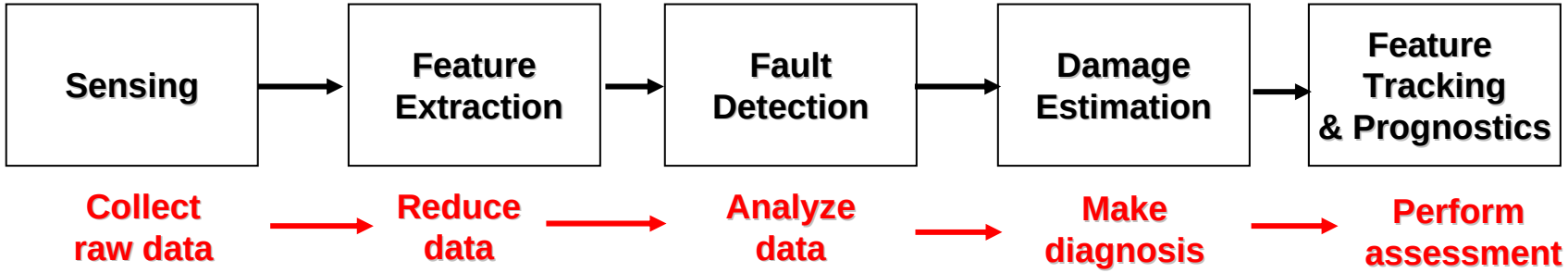
Integrated Systems Health Management Engineering

Systems Engineering

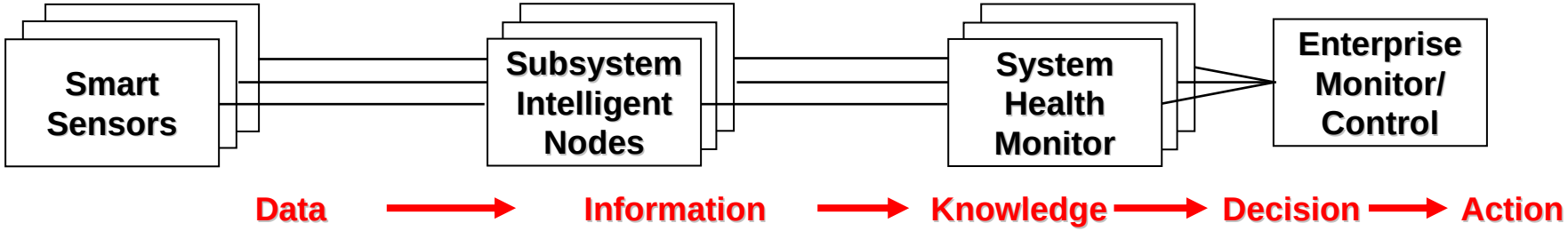


Open Systems Architecture

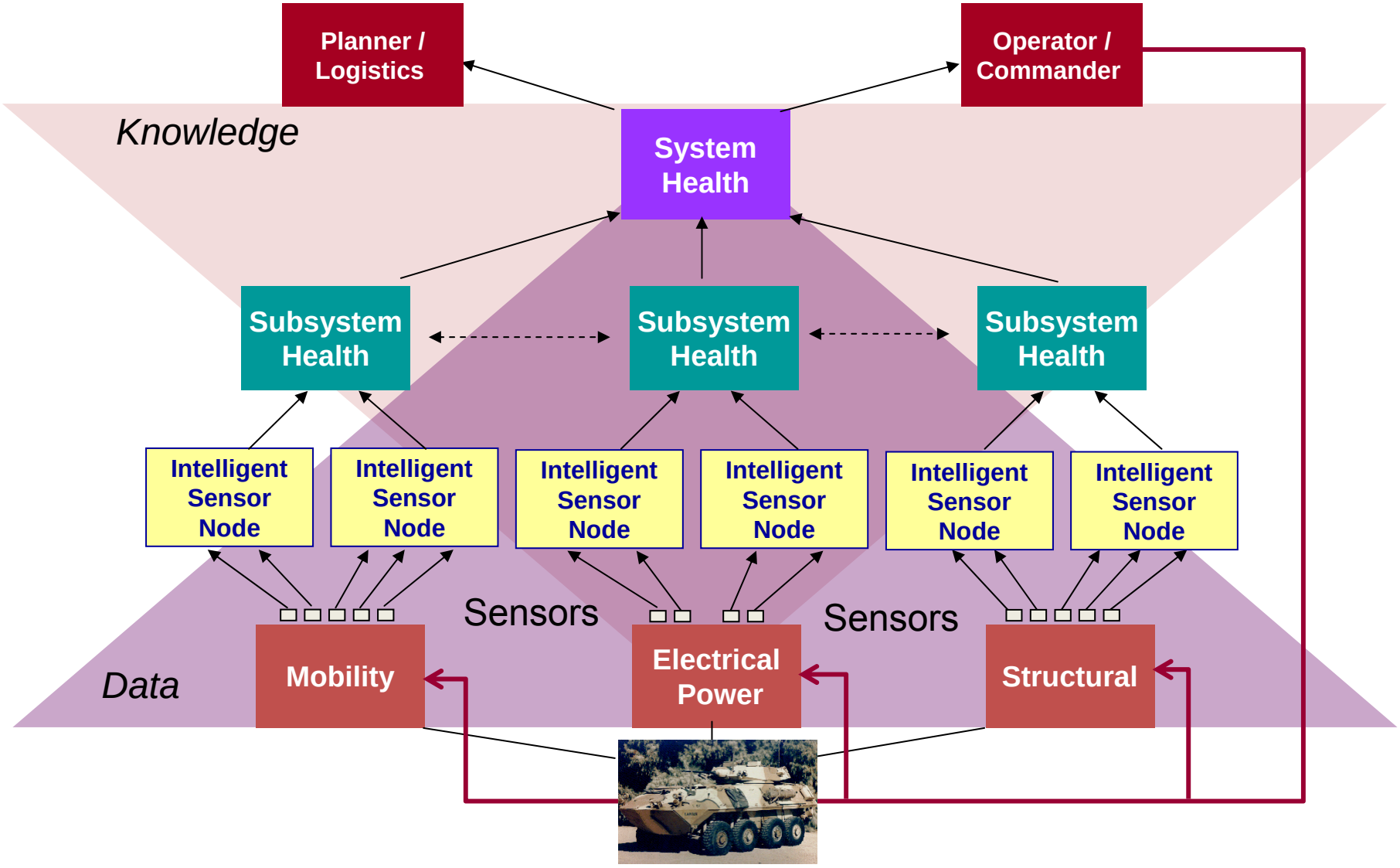
Science



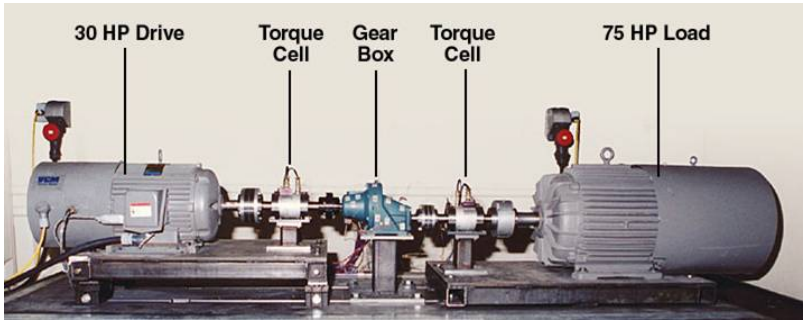
Technology



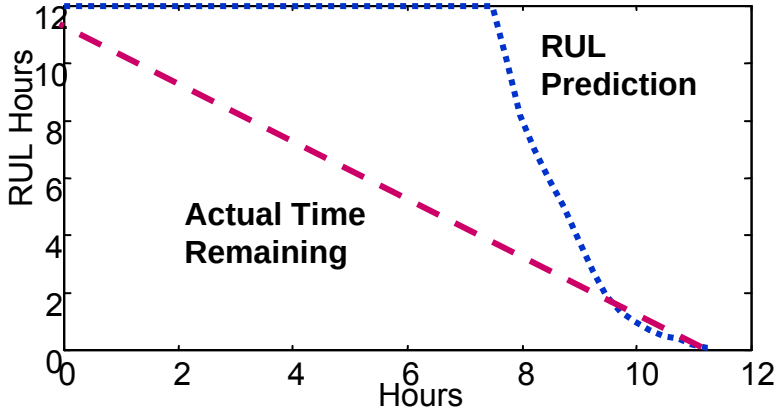
System Architectures for Information Management

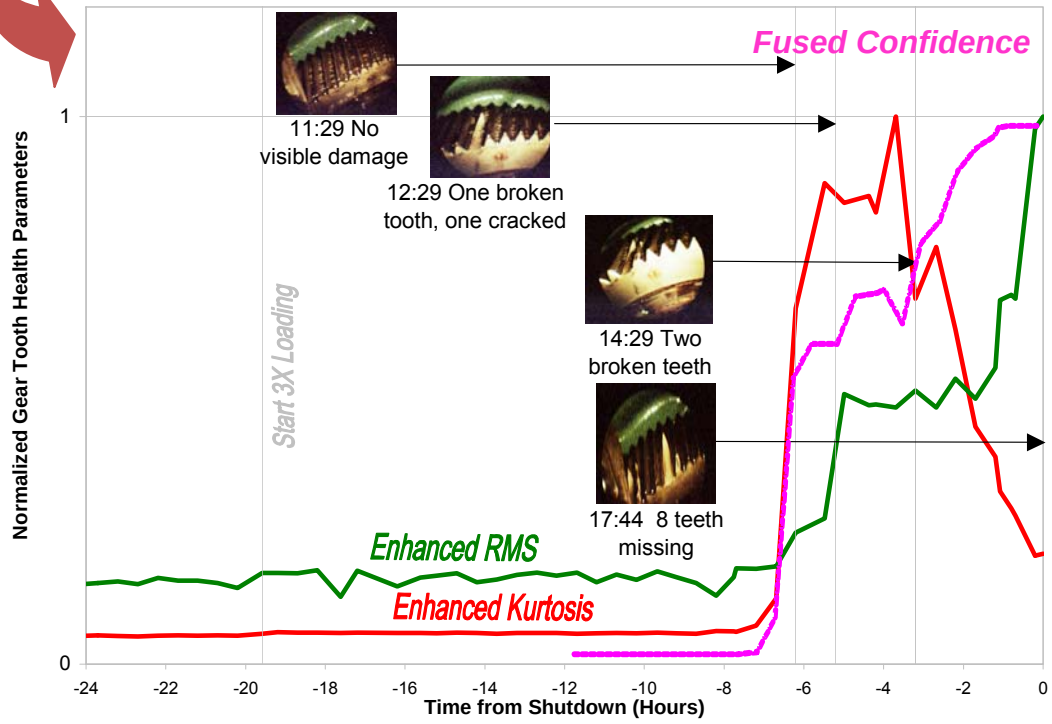


Diagnostic and Prognostic System Development



Mechanical Diagnostic Test Bed



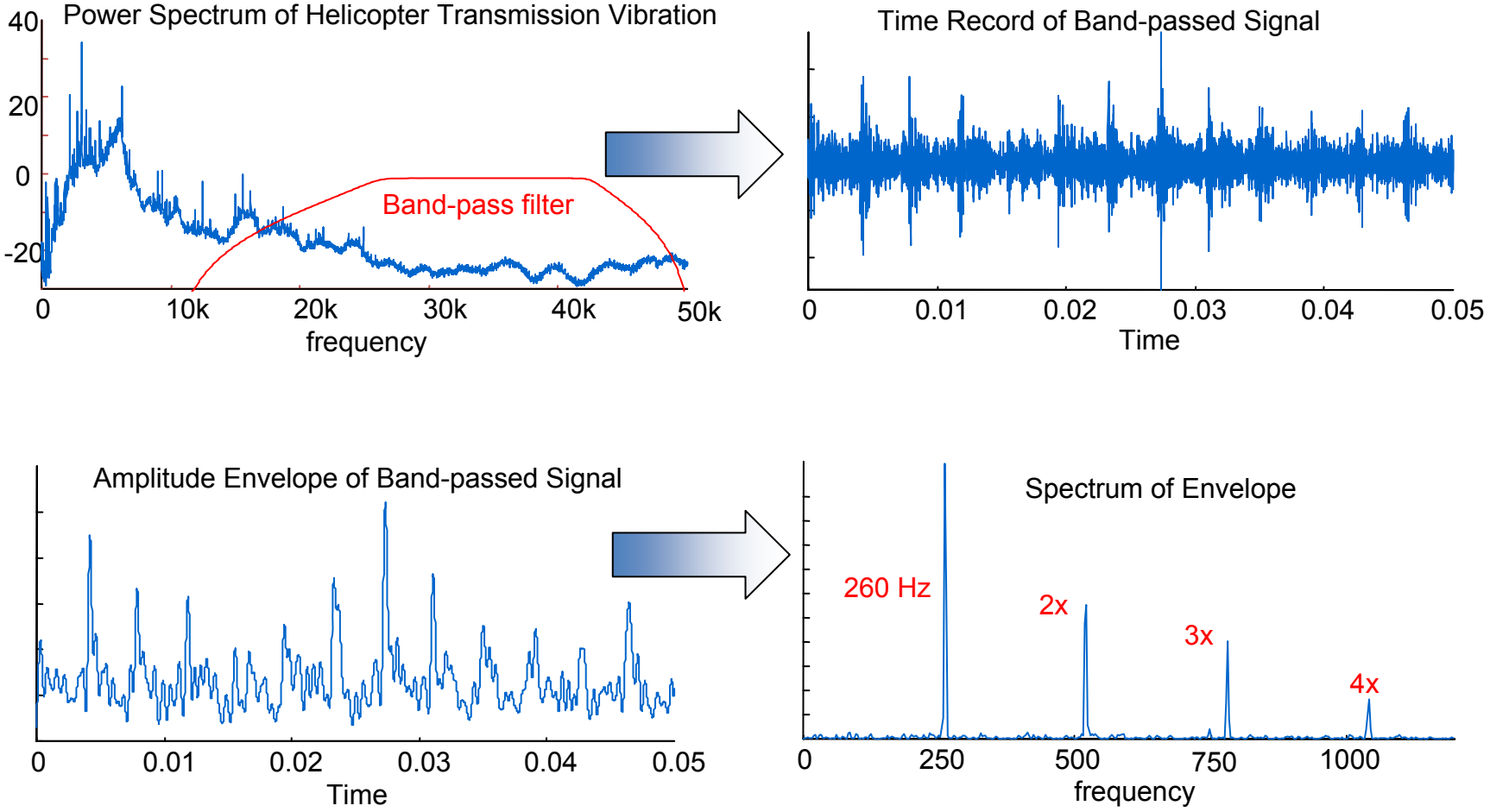


RUL= Remaining Useful Life

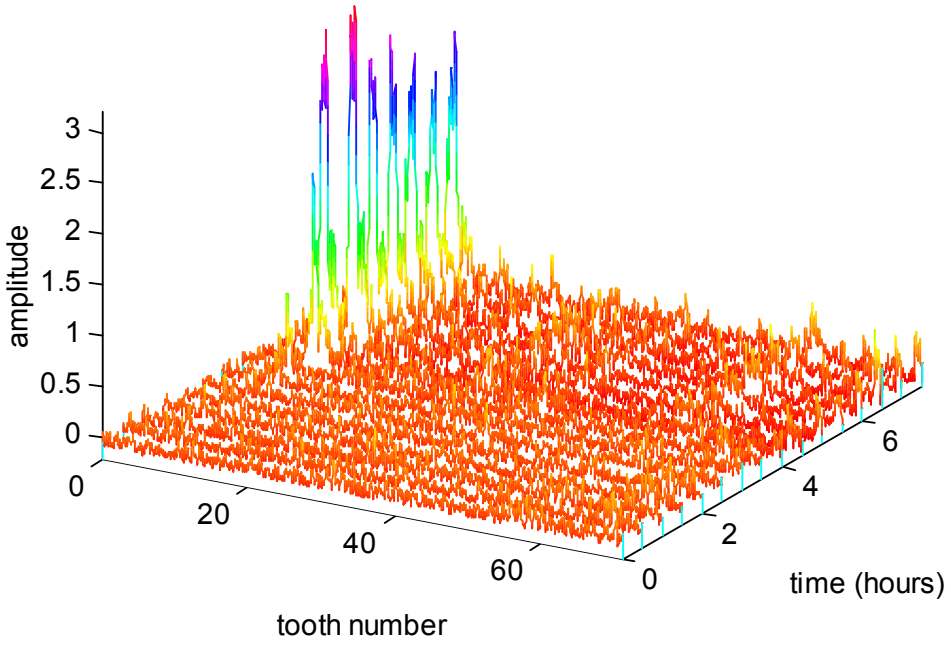
Knowing the gearbox configuration, we monitor vibration and apply techniques to detect, isolate, and track fault progression.

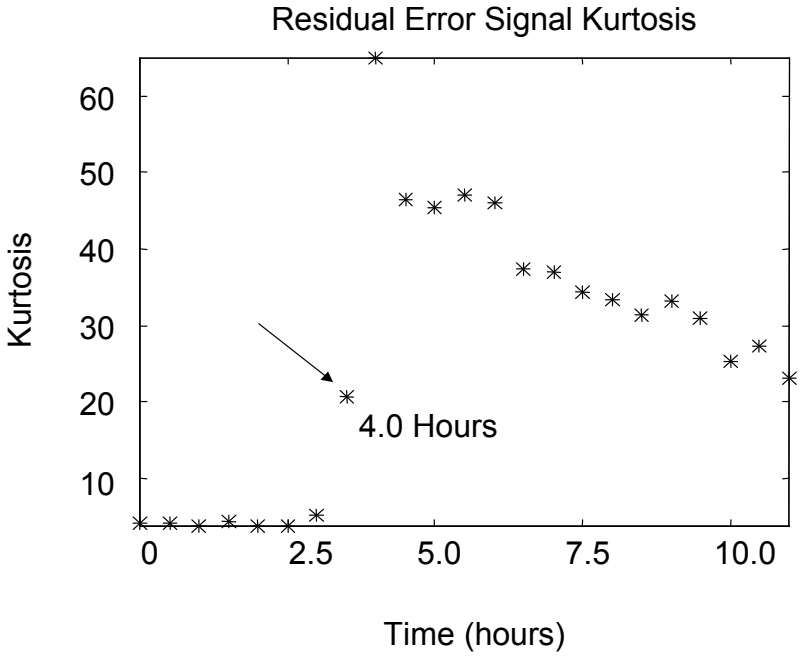
Physics-based Processing

Frequency-Band Enveloping – used in bearing fault detection



Wavelet-Based Residual Signal Analysis

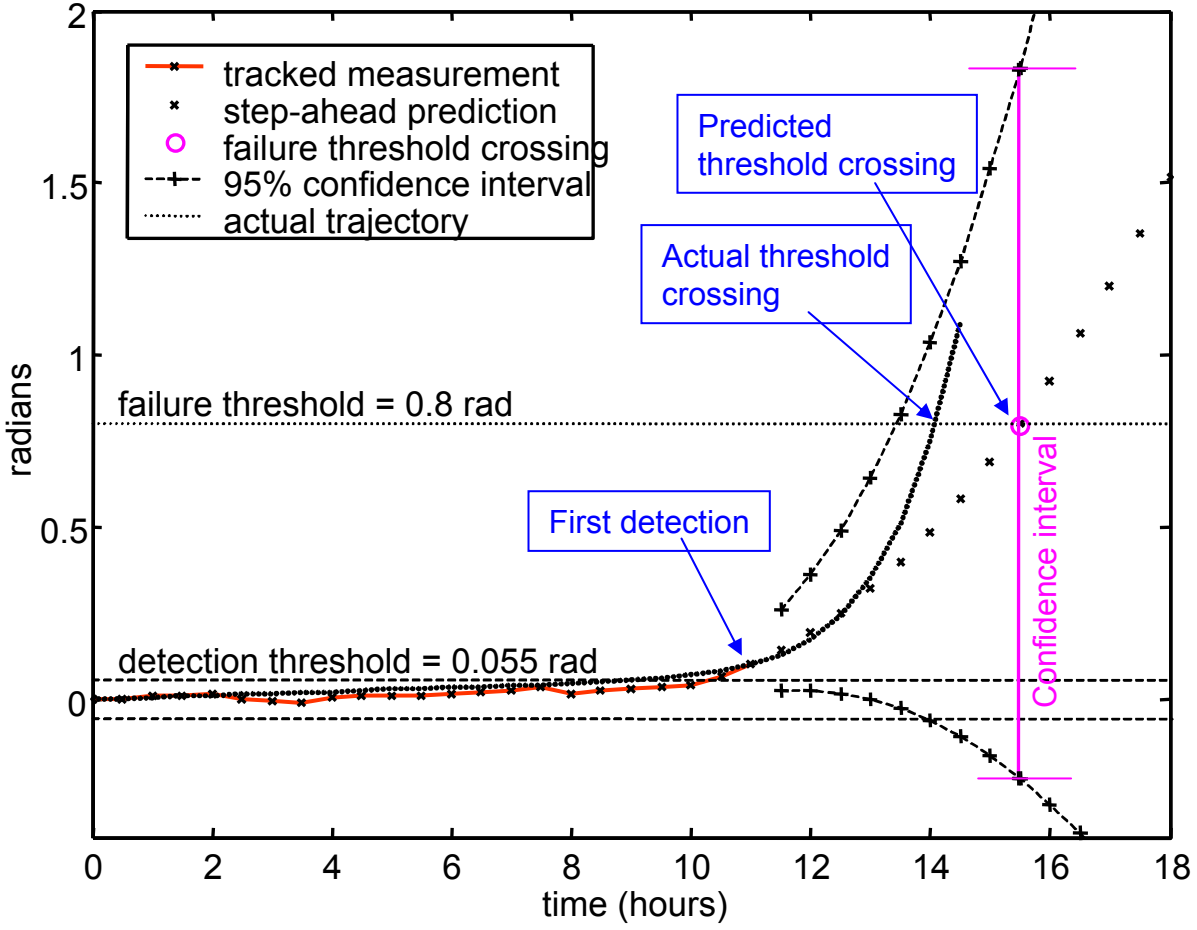




Wavelet-based analysis used to compute residual vibration signal associated with structural defect in gear tooth

Statistical analysis of residual signal indicates onset of damage

Dynamic Prognostic Models



First detection @ 11 h

Time to failure threshold crossing:

prediction = 4.5 hours

95% conf. = ± 1.0 rad

actual = 3.1 hours

- Data-driven prognostic techniques depend on the dynamic characteristics of the fault propagation process
- Prediction accuracy depends on prediction horizon and statistical characteristics of uncertainty in calculated feature

Battery Prognostic Processing Architecture

Ex, Sn

Impedance Processing

Electrochemical Model Identification

Feature Vector Files

SOC, SOH, and SOL Estimators

ARMA

Fuzzy Logic

Neural Network

SOC, SOH, SOL Estimation FIles

Decision Fusion

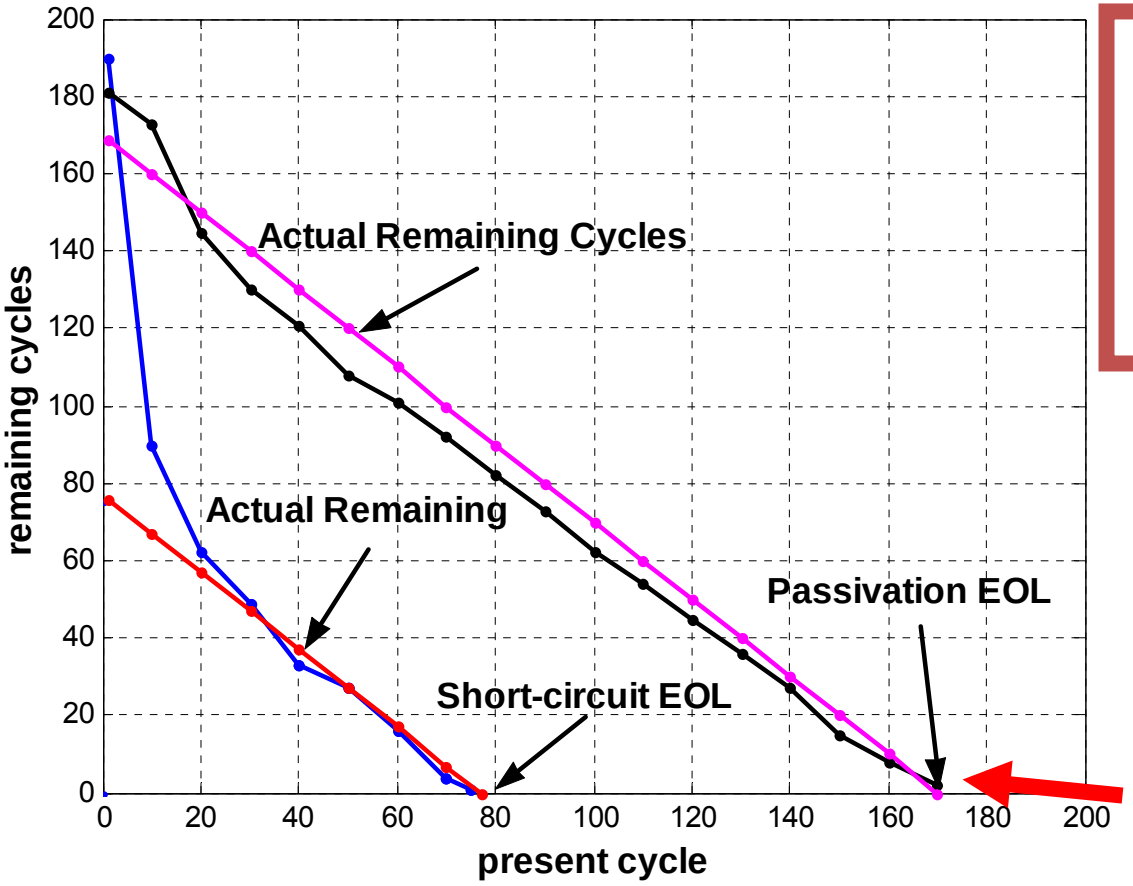
History Knowledge

if,...then

User Info File

User Interface

Key to Prognostics: Failure Mode Identification



Same type of battery
Same operating conditions
Different failure modes
Different end-of-life points

Other scenario:

Same type of battery
Same failure mode
Different operating conditions
Different end-of-life points

More than double the cycles!

Bottom Line: Sometimes it's not enough just to say system is starting to fail ("Does that mean you have 80 cycles or 170 cycles remaining?")

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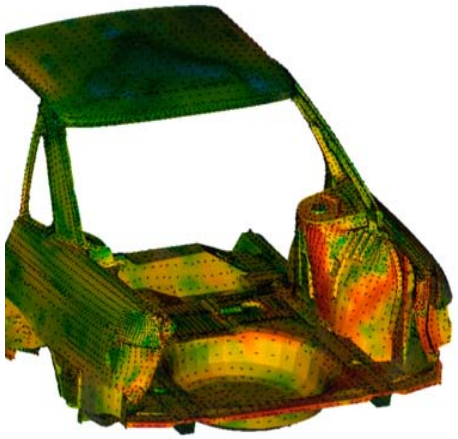
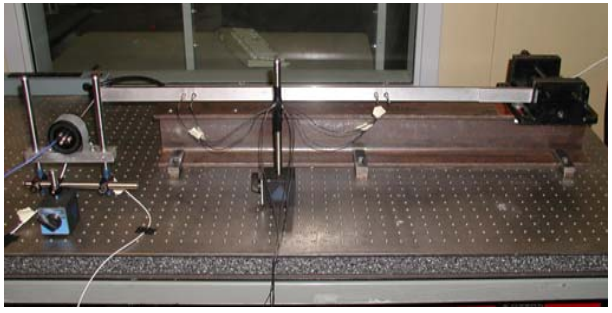
Structural Intensity Based SHM

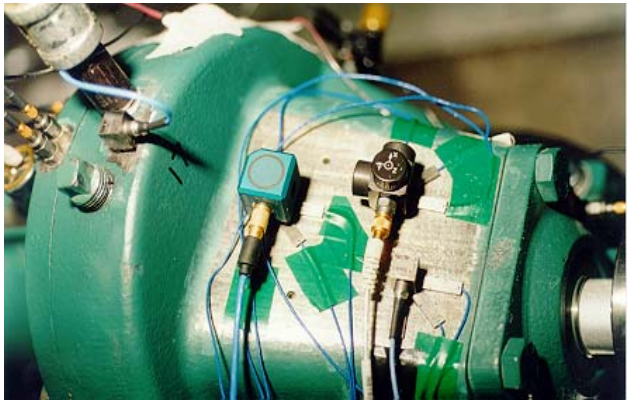
- Build on experimental & modeling experience
  - Vibration control / Structural Intensity FE applications
  - Machinery CBM Surface Structural Intensity (SSI) experimental applications
  - Traditional vibration based SHM methods



Computational (FEM) Prediction of Energy Flow in Complex Structures for Vibration Control



Measurement of (Power) Energy Flow of Beam Structures for Damage Detection



Measurement of Structural Surface Intensity on Machinery Gear Box for Detecting Internal Damage

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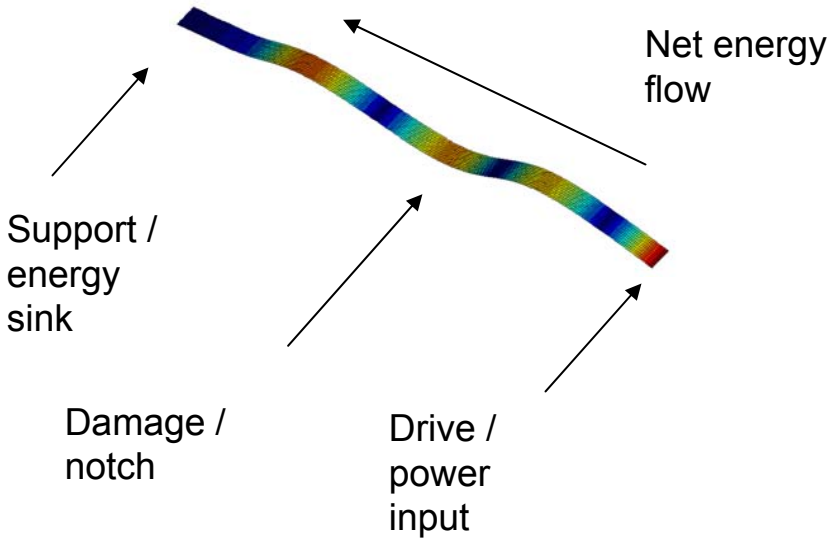
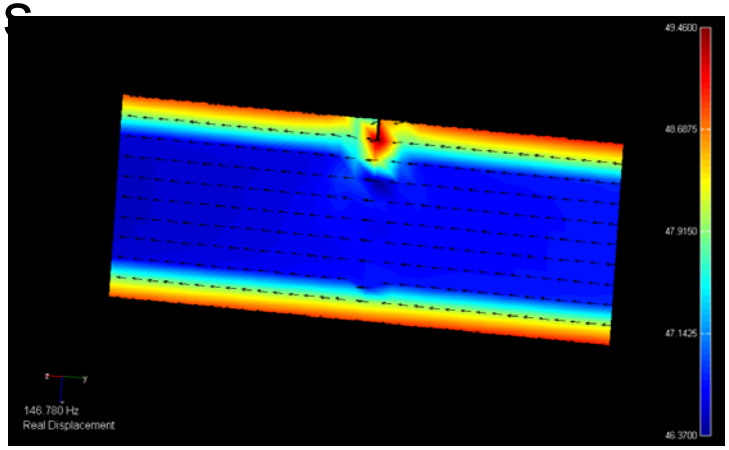
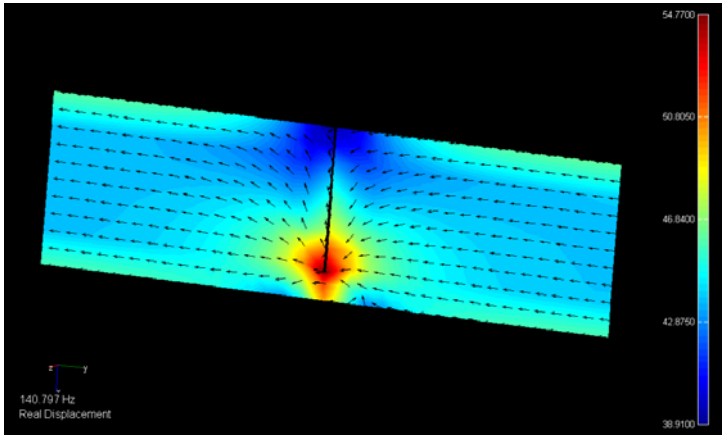
Structural Intensity Based SHM

- Simulation using FE based models





SI Small Notch



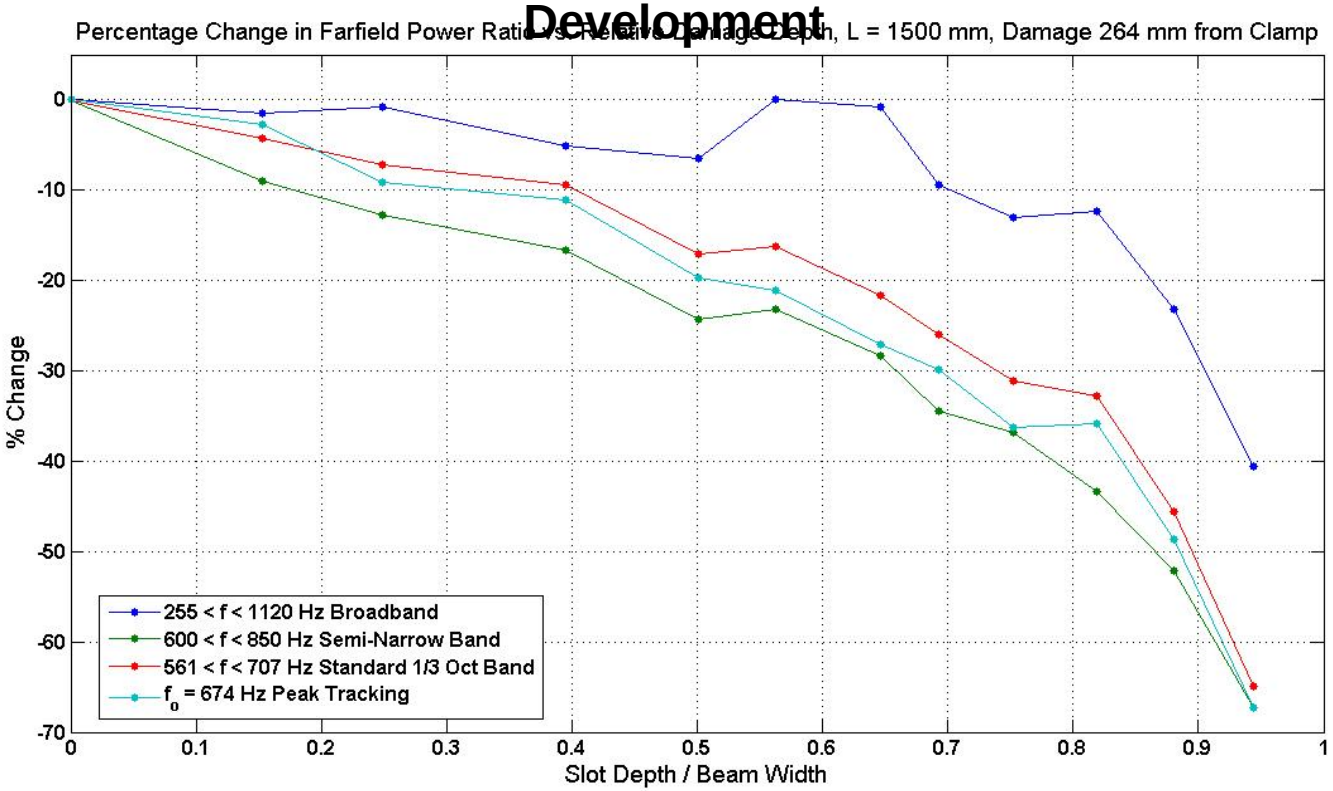
SI Large Notch

Structural Intensity Plots of Damaged Beam Section

- Unit vectors indicating intensity direction
- Color bar indicating intensity magnitude
  - Note: Scales not the same on two plots
- Net energy flow right to left
- Pure Bending vibration for these two cases

Structural Intensity Based SHM

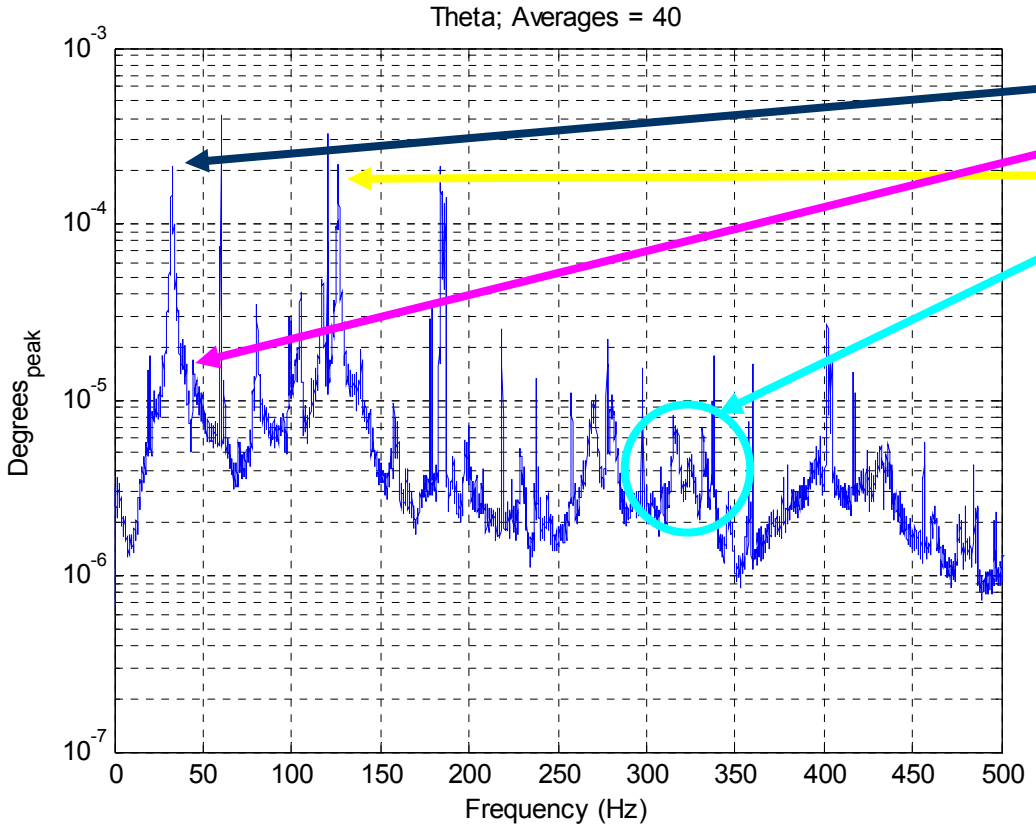
Simplified Structure Experiments: Signal Processing Techniques Development

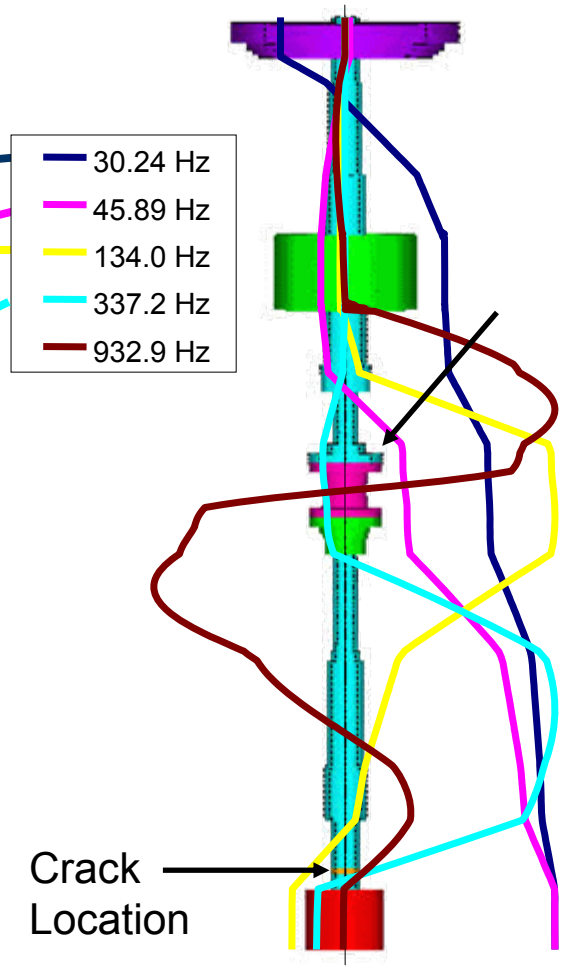


- Each band type reflects significant power flow changes
- Semi-Narrow, 1/3 Oct, and Peak Tracking band trends typically develop at lower severities than Broadband trends
- Broadband results dominated by high powers at low frequencies → masking of high frequency, low power effects
- Typical healthy to fully damaged power ratio changes ~ 20 – 70%
- Typical healthy to fully damaged resonance frequency shift ~ 1 – 7%

Shaft Crack Monitoring

- Unable to detect the low amplitude shaft modes which exhibit the highest crack sensitivity as seen by Finite Element Modeling. - (Example: Mode 4)
- May be located in the noise floor content.



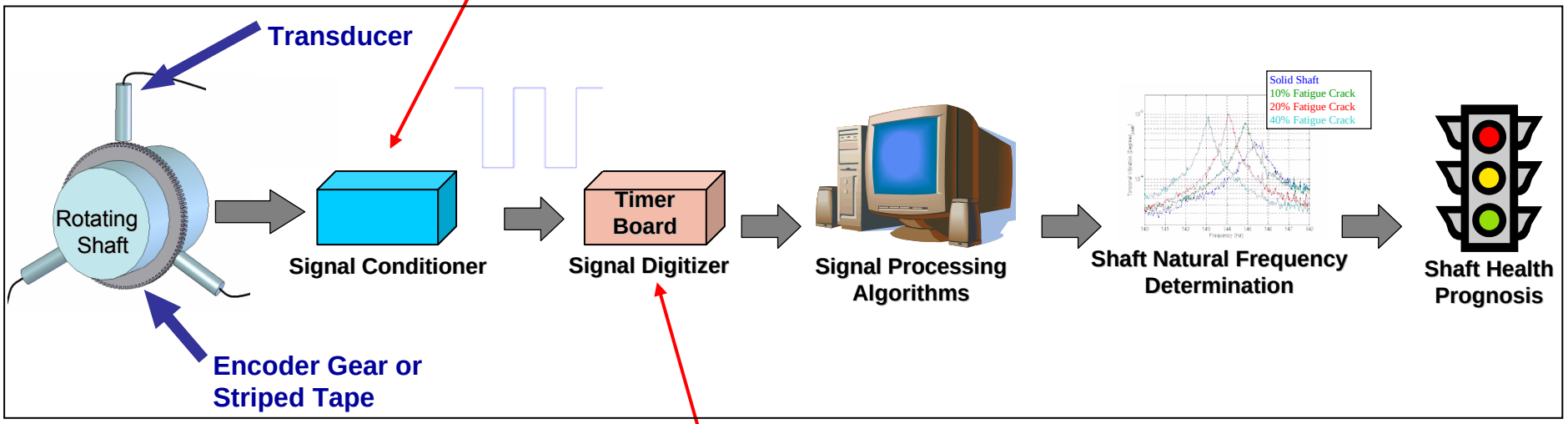


General Approach

TVA Installation Specifics

Monarch Instrument
MT-190W Magnetic Sensor

Detects signal zero crossings for analog square wave (TTL 0-5 VDC) conversion of sensor waveform for use in timer board. Also a line driver ensures signal travels required distance to sensing computer (~1000 ft).



200 toothed encoder gear, evenly spaced teeth, 13/64" tooth/gap width, ¼" depth

NI PCI-6602 Timer Board
(80 MHz clock rate)

Records the number of timer board cycles between each zero crossing. This data can be transformed into each individual tooth/gap crossing time.

Drivers for System Health Management

- Safety – early work in helicopter HUMS
- Maintenance – use HUMS to enable condition based maintenance (CBM)
- Manning – reduce manning through CBM and PHM
- Life Cycle Cost – reduce total life cycle cost through savings in maintenance, manning, and sustainment
- Logistics – extend savings through the enterprise by leveraging CBM and PHM across fleets of assets
- Asset Capability Management – manage asset health by matching mission requirements to capability
- Intelligent Systems – enable autonomous and automated response to changing external and internal operating conditions