Prognostics: Recent Achievements and Future Challenges

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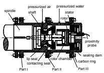
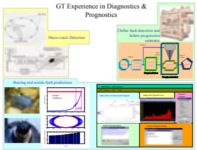
Capabilities:

- Prognostics Laboratories
  - Phenomenology– Seals and Bearing Lab and Test Rigs
  - Sensors (Eddy Current, Pressure, Temperature, Accelerometers, Acoustic Transducers, etc.)
  - Real-time Diagnostics and Prognostics Systems
- MEMS Technology Laboratories
  - High Temperature Environment
- Rapid Prototyping Facility
- Evolutionary Algorithm Development Laboratories
- Direct Experience with Ground Vehicles and Aircraft
- Advanced Signal Processing and Feature Extraction

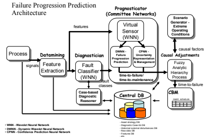


Instrumented Mechanical Face Seal Test Rig

GT Experience in Diagnostics & Prognostics

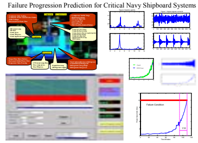


Failure Progression Prediction Architecture



Prognosticator (Committee Networks)
Scenario Generator - Extreme Operating Conditions
features
Virtual Sensor (WNN)
Process
signals
Datamining
Feature Extraction
Diagnostician
Fault Classifier (WNN)
DWNN - Failure Progression Prediction
CPNN - Uncertainty Representation & Management
causal factors
Causal Adjustments
Fuzzy Analytic Hierarchy Process
time-to-failure/time-to-maintenance
time-to-failure
Case-based Diagnostic Reasoner
Central DB
CBM
• WNN - Wavelet Neural Network
• DWNN - Dynamic Wavelet Neural Network
• CPNN - Confidence Prediction Neural Network

Failure Progression Prediction for Critical Navy Shipboard Systems



Proposed Optional Application Domain:

Application: Propulsion Systems

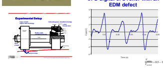
Mechanical Face Seals

- Most Effective for high pressure, high temperature, high speed (i.e., high performance) applications.
- First in the "line of defense" (protect gears, bearings, etc.)
- Are bound to fail!

New Sensor Concept Applied to Monitoring of Roller Taper Bearings

Non Vibrating Contact Potential Difference (CPD) Sensor

CPD signal of a roller with an EDM defect



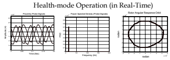
Sensors & Sensing:

Loss of Functionality: Material Degradation, Face Wear, Cracking, Deformation, and Blistering.
Use Sensors for Diagnosing Failure Onset,
Apply Life Estimations, Apply Active Control
for Life Extension and Restore Functionality.

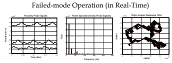
Sensors:

- Eddy current proximity probes, thermocouples, pressure transducers → apply sensor fusion.
- Prefer mature/proven technology.
- Commonly employed in high-speed turbomachinery.

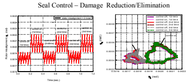
Health-mode Operation (in Real-Time)



Failed-mode Operation (in Real-Time)



Seal Control – Damage Reduction/Elimination

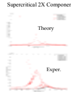


Controlled Seal:

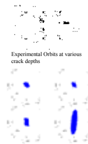
- Rotor better tracks stator misalignment
- Virtual elimination of higher harmonic oscillations
- Closer to circular orbits, i.e., noncontacting operation

Multi-Fault Prognostics System: Crack Detection in Seal/Rotor Driving Shaft

Supercritical 2X Component

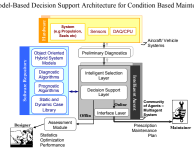


Experimental Orbits at various crack depths



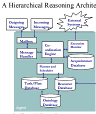
Reasoning Architecture:

Model-Based Decision Support Architecture for Condition Based Maintenance



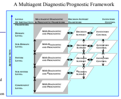
Hardware
System (e.g Propulsion, Seals etc)
Sensors
DAQ/CPU
Aircraft/ Vehicle Systems
Software Repository
Object Oriented Hybrid System Models
Diagnostic Algorithms
Prognostic Algorithms
Static and Dynamic Case Library
Preliminary Diagnostics
Intelligent Selection Layer
Decision Support Layer
Interface Layer
Intelligent Agent
Online
Offline
Community of Agents – Multiagent System
Designer
Assessment Module
Statistics Optimization Performance
Prescription Maintenance Plan
Maintainer

A Hierarchical Reasoning Architecture for Failure Progression Model Predictions



An Intelligent Agent

A Multiagent Diagnostic/Prognostic Framework



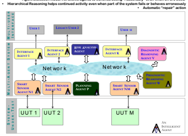
Intelligent Multiagent Systems

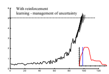
- Hierarchical Reasoning - Janus Effect; Near Decomposability; Part-Whole Relationship
- Distributed Knowledge-base; Hierarchically Organized
- Fault-Tolerant - Agents designed to detect faults and reconfigure functions appropriately
- Deployment of Agents at Multiple Levels of Abstraction

Error-Tolerant Multi-Agent Architecture:

Runtime Error-Tolerance

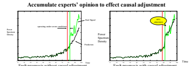
- Does not assume that peer agents and user will be error-free
- Agent execution model that allows agents to continue acting "reasonably" even when errors occur
- Hierarchical Reasoning helps continued activity even when part of the system fails or behaves erroneously
- Automatic "repair" action





Prognostic Results - Uncertainty Management/ Accounting for Extreme Operating Conditions

Accumulate experts' opinion to effect causal adjustment



Fault prognosis without causal adjustment

Fault prognosis with causal adjustment