Intelligent tools for Prognostics Health Management and its application to Avionics

Prognostics and Health Management for Electronic Systems Workshop

CALCE August 24 2004

Smiths Aerospace proprietary information.
Overview

- Smiths current work on Mechanical systems Prognostics
  - ProDAPS Program Information
  - What does ProDAPS do?
  - ProDAPS Key characteristics

- Example of ProDAPS Application

- ProDAPS Components
  - Causal Network editor
  - Data Mining

- Example of a Decision Scenario for Electronic Components

- Summary
<table>
<thead>
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<th>ProDAPS Program Information</th>
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<tr>
<td><strong>ProDAPS = Probabilistic Diagnostic and Prognostic System</strong></td>
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<td><strong>Dual Use Science and Technology Program, targeted at gas turbine engines</strong></td>
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<td>- Phase I: 2000-2002 (Final Demonstration end October 2002)</td>
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<td>- Phase II: 2003-2005</td>
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<td>- Pratt &amp; Whitney program support</td>
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<td><strong>Key program milestones:</strong></td>
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<td>- Develop and demonstrate ProDAPS concepts (completed)</td>
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<td>- Develop and demonstrate key ProDAPS tools (completed)</td>
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<td>- ‘Off-line’ analysis of USAF F100-229 data to demonstrate benefits (current task)</td>
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<td>- ‘Real-time’ analysis for USAF evaluation</td>
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What Does ProDAPS Do?

- Uses advanced AI tools to provide a probabilistic, knowledge rich, framework to do the following:
  - Integrate all available types of data
  - Provide advanced data analysis capabilities to maximize the available information
  - Fuse and reason with data from all sources to provide accurate diagnostics and prognostics
  - Support the user in optimum decision making
  - Adapt and improve its performance through the mining of historical data to discover new knowledge

- Provides a flexible, component based, architecture where components can be configured for specific applications
PHM needs addressed by ProDAPS

Requirements drivers
- Current high military engine sustainment costs, with many engines falling short of reliability goals
- Need to achieve the goal of ‘Affordable Readiness’
- This requires Proactive Engine Management, which in turn needs good information

Specific challenges:
- Inadequate approaches to high level data fusion and reasoning
- Need for information for prognostics and decision making
- Lack of tools to support decision making

Technology needs
- PHM can be aligned with the Condition\Convenience Based Maintenance (CBM) philosophy
Positioning ProDAPS within the OSA-CBM Architecture (an Open System Architecture developed by Boeing and 10 other organizations)

- ProDAPS provides the high level intelligent functions and capabilities needed to move technology from health monitoring (e.g. HUMS) to true IVHM/PHM systems

- Current capability gap, and key target area for ProDAPS intelligent systems tools, e.g.
  - Data fusion
  - Automated reasoning
  - Data mining (for empirical models)

- Existing Smiths HUM systems provide considerable functionality in these areas

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<th>ProDAPS functional hierarchy</th>
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<td>1. Data Acquisition</td>
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<td>2. Data Manipulation</td>
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<td>3. Condition Monitor</td>
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<td>4. State Detection</td>
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<td>5. Prognostics</td>
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<td>6. Decision Reasoning</td>
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<td>7. Presentation Layer</td>
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ProDAPS components

- Causal Networks for probabilistic diagnostic and prognostic reasoning
- Embedded reasoning for on-board applications
- Powerful Data Mining Facility with advanced learning algorithms (Web enabled for remote access)
- Influence Diagrams for Decision Support

- Al-based data mining, data fusion, reasoning and decision support technology to provide advanced health management capabilities
- Tools and software components to enable technology insertion into multiple legacy and future on-board and ground-based platforms
- Tools conform to open standards

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Concept of ProDAPS component configuration for IVHM

- **ProDAPS Ground-based Fusion & Reasoning**
  - Diagnostics
  - Prognostics
- **ProDAPS Embedded Fusion & Reasoning**
  - Diagnostics
  - Input to Autonomous Controls
- **ProDAPS Decision Support**
  - Recommended actions
  - Autonomous control
- **ProDAPS Data Mining & Anomaly Detection**
  - New knowledge
  - Anomaly models

On-board components applicable to:
- In development a/c
- Future a/c

Ground-based components applicable to:
- Legacy a/c
- In development a/c
- Future a/c

On-board components applicable to future a/c

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Maximize information from all available relevant sources to derive actions that satisfy system level goals – these goals are sub-goals of more generic ones: safety, reliability, mission readiness, cost optimization.

ProDAPS applies advanced pattern recognition tools

- Advanced thresholding
- Probabilistic clustering
- Association rules
- Decision trees

Features and Propositions that summarise and characterise the data

Raw data from Sensors Histories Crew reports

Information Level I (Situation Assessment)

- Causal networks
- Propositional inferencing for explaining away

Causal networks influence inferencing Plan inferencing

ProDAPS applies intelligent reasoning tools

ProDAPS applies intelligent decision tools

Use system objectives/constraints to extract Information Level II

Actions (Recommended Autonomous)

Diagnostics -> Prognostics
Situation Assessment -> Readiness Assessment

more intelligence = increased benefits
Example of ProDAPS Application
An introduction to electrostatic sensing technology

- Sensors detect electrostatically charged debris
- As charge passes the sensor it is induced on sensor face
  - Signal conditioning produces a voltage pulse which is processed in real-time
- Sensors used for engine Gas Path Monitoring
  - Ingested Debris Monitoring System (IDMS) – inlet
  - Engine Distress Monitoring System (EDMS) – exhaust
- ‘Normal’ background level charge:
  - Average dust levels (inlet)
  - Combustion products (exhaust)
- Additional charges produced by:
  - Foreign Objects (inlet)
  - Component debris, e.g.
    - Hot section erosion (exhaust)
    - Abradable seal rubs (exhaust)
    - Combustor burning / material loss (exhaust)
  - Fluid contamination (foreign or domestic)
    - Carbon, soot
    - Unburnt fuel
    - Sand, dust
    - Moisture, salt water
Engine gas path monitoring (IDMS & EDMS) system overview

IDMS FOD: 2 ring sensors installed on the inlet
IDMS Dust: 1 sensor on the inlet (ring or button)

EDMS: Button sensor installed in exhaust duct

Data acquisition and processing:
Airborne or ground based system
Stand alone or integrated
EDMS/IDMS feature extraction
Correlation of EDMS / IDMS with engine operation / flight data
Output key features / diagnostic / prognostic data
Complexity depends on monitoring requirements

System Level Data Fusion:
EDMS/IDMS key features / diagnostic / prognostic data fused with higher level engine / aircraft and other PHM sensor information for system level health management

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IDMS & EDMS for IEPHM program

- Demonstration of IDMS/EDMS single card processing solution.
  - Implementation included automated IDMS/EDMS diagnostics.
- ProDAPS Network Editor was used to create a causal network for embedded reasoning on Smiths gas path electrostatic data.
- Causal Network implemented on Smiths airborne PHM processor module.
- IDMS/EDMS diagnostic output passed to higher level data fusion for overall engine diagnostic.

**Example IDMS/EDMS causal network design**

- Smiths PHM processor module

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Advantages:

- Knowledge and data are combined for reasoning
- Reasoning can be cause to effect and effect to cause
- Still reasons when some data is missing, can predict expected outputs
- Uses sound probabilistic theory

High level fusion/reasoning to generate a prognostic engine health index and system level events.

Fusion/reasoning based on Smiths Causal Networks, which are Bayesian networks.
ProDAPS Decision Support

- ProDAPS supports the user in making optimal maintenance decisions.
- All reasoning is automated but the user has the opportunity to play ‘what-if’ scenarios.
- ProDAPS combines PHM information with costs/rewards to recommend maintenance related actions.
- Operational factors are also modeled.

- ProDAPS decision support uses Decision Networks plus Association Networks to manage dynamic costs.

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ProDAPS Network Editor

- ProDAPS tool for creating, managing and updating Bayesian networks
- Used for creating two types of network:
  - Decision Networks for decision support
  - Causal Networks for diagnostics and prognostics
- Key features
  - Flexible network configuration and testing tool
  - Can handle large networks and multiple sub-networks
  - Highly optimized inferencing
  - Can output C code for embedded applications
- Demonstrated using P&W fault-event data
ProDAPS uses a collection of Smiths built components to support data mining.

Components provide data mapping, integrity checking, cleaning, feature extraction and learning.

Knowledge is updated when discovered patterns can be linked to faults or explained.

Patterns which cannot be explained are treated as anomalies and are tracked to monitor any development.
Data Mining

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Reasoning Function
Decision Making Scenario Example

- **Failure Mechanisms**
  - (t1, t2, ..., tn)
  - Solder joint

- **Cost Models**
- **Failure Index**

- **Temperature**
- **Vibration index**
- **Relative Humidity**
- **Stress rate**

- **Decision node**
  - Time to Fail Solder joint
  - Time to fail for LCR
  - Time to fail for PLCC

- **Decision node**
  - Replace Card
  - Repair Card
  - Replace Joint

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Summary

- **ProDAPS provides intelligent tools to facilitate:**
  - the extraction of new knowledge and information from system health data,
  - reasoning with this knowledge and information to diagnose system state
  - anomaly detection and trending for prognostics
  - determining the optimum actions to meet system management goals.

- **The ProDAPS tools are being developed as an Open System Architecture:**
  - Updateable with new knowledge gained from experience
  - Adaptable to allow for updated subsystems.

- **ProDAPS has a user friendly decision support function that can be customized for different scenarios. Different types of decision nodes can be modeled using the network tool.**

- **The inputs to the ProDAPS decision tool could be different failure models for each one of the structures, parts, etc, the classification of the failure mode, time to failure, the output of the cost model, environmental conditions (temperature, humidity, pressure, etc), etc. The output could be a recommendation for a maintenance action, an index of health, prognostic of an imminent failure**