Predictability in Space Launch Vehicle Anomaly Detection Using Intelligent Neuro-Fuzzy Systems

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Joint Effort

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INTelligent NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

742 TOTAL FLIGHTS (1966-87), 58 failures

PASSIVE SYSTEMS

ACTIVE SYSTEMS

OTHER (6)

NON-SYSTEM OR UNKNOWN

VEHICLES: ATLAS, THOR/Delta, TITAN, SCOUT, STS

Where The Flight Failures Have Been In Launch Vehicles
INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

STS LAUNCH DELAY ASSESSMENT (AS OF JAN 24 1992)

- DOOR HINGES: 45
- LH2 LEAKS: 301
- MPS: 19
- HYPER: 26
- SSML: 192

45 LAUNCHES
- 9 ON TIME
- 55 W DELAY
- 87 ATTEMPTS

NOTE: DELAYS OF ONE DAY OR MORE

CUMULATIVE DELAY TIME (DAYS)

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>NO. OF DELAYS</th>
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<tbody>
<tr>
<td>SRB</td>
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<tr>
<td>LIQUID PROPULSION</td>
<td>15</td>
</tr>
<tr>
<td>FLIGHT HARDWARE</td>
<td>12</td>
</tr>
<tr>
<td>GSE</td>
<td>5</td>
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<td>WEATHER</td>
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<td>RANGE</td>
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<td>OTHER</td>
<td>32</td>
</tr>
</tbody>
</table>

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Breakdown of Operations Hours

- FLUIDS AND PROPULSION SYSTEMS ACCOUNT FOR HALF OF ALL TESTING HOURS.

Chart showing:
- FLUIDS & PROPULSION: 52%
- MECHANICAL: 22%
- AVIONICS: 18%
- MISC.: 8%

ACS: 12%
HYDRAULICS: 11%
PNEUMATICS: 29%
PROPULSION: 29%
PROPELLANT LOADING: 19%
Troubled Spacecraft

A federal panel Wednesday announced the findings of its inquiry into the Aug. 21 disappearance of the $980 million Mars Observer spacecraft. Exactly what happened to the space probe is not known, but the independent panel found these problems:

- **Mechanical flaw:** A leak of volatile hydrazine fuel may have caused an explosion when the spacecraft’s tanks were pressurized.

- **Design flaw:** NASA engineers used technology that had been developed for operation in near-Earth orbit but was unsuitable for the more extreme conditions of interplanetary space.

- **Management flaw:** Project managers at the Jet Propulsion Laboratory did not exercise sufficient control over continuing changes in the spacecraft’s design and its scientific instruments.

Source: NASA
INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

No sensors or data processing capability. Mission loss when failures occur.

Sensors at a few critical points only, some failures detected & correctly repaired.

Too many sensors cause repeated false alarms and sensor (not function) failures. Overcomplicated processing capability costs too much to build with little gain.

Adequate sensor suite catches critical and probable failures without too many false alarms. Data processing isolates sufficient failures without excessive false alarms.

VHM COST OPTIMIZING CURVE
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TARGET HMS - STS Auxiliary Power Unit Location
AUXILIARY POWER UNIT

- Provide power for the Orbiter hydraulic systems
  - liquid hydrazine \rightarrow mechanical shaft power

- Hydraulic systems
  - actuate the Orbiter aerosurfaces
  - throttle and steer Orbiter main engines
  - deploy and steer landing gear
  - apply landing gear brakes

- Operation Cycle
  - t-5 min to OMS-1 burn
  - deorbit burn and entry to just before landing
INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

- Monitoring fuel tank isolation, fuel control valves and electronic controller, e.g.,
  
  - valve open for > 2 min in orbit without fuel flow could detonate hyrazine near valve
  
  - leakage detection
  
  - high rpm pulser-type valves

APU MONITORING AND DIAGNOSIS
INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

TECHNOLOGY ISSUES

- Engineering alarm limits - critical thresholds which define the acceptable range of engineering values on any telemetry channel
  - determined manually: hardcopy ISOE data, design information on spacecraft, rules of thumb
    - Overreliance on domain experts leading to wide thresholds creating a range of undetected anomalies
    - monitoring of individual sensors via redlining approach
- Access only to snapshots of telemetry due to exploitation of low sensor acquisition rates. Further degradation due to noisy and incomplete data
- Specific diagnostics can be executed only if they were preconceived and preprogrammed
  - cannot currently correlate effects between multiple sensors in real-time
  - fault-detection to engine catastrophe time can be as short as 0.1 sec.
Integration of Neural Networks & Fuzzy Logic

NASA JSC, McDonnell Douglas

FUZZY LOGIC
- raw telemetry data
- linguistic state variables

NEURAL NETWORK
- nonlinear transformation
- linguistic fuzzy state variables

JPL

FUZZY LOGIC
- events
- System State table

NASA JSC, JPL, Lockheed

generate lookahead trajectory to fault states

output probability of system failure in flight

Sensor_1
- ...
- ...
- ...

Sensor_k

- 100 Hz
- linguistic space
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STS / APU HEALTH MONITORING

- detection of all red line errors currently identified
- real-time correlation of data from multiple heterogeneous sensors
  - faster-than-real-time anomaly propagation to determine probability of failure
  - both with (using NN s/w) and without (using NN h/w) time-lags
- ease of augmenting expert-generated APU fault knowledge base without needing to redesign the system
- isolating failed sensors as against failed subsystem / system
  - reconstruct suspect information and minimize disruption of diagnostic process
- synergistic integration of fuzzy logic and neural networks for real-time diagnostic applications
INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

STS / APU HEALTH MONITORING

- Startup & mode-switch phases difficult to monitor due to highly complex & nonlinear nature of IAPU dynamics

- reduced engine / test stand damage during test firings
  - typically damage 1 APU every 2 weeks

- facilitate post-test diagnostic process
  - tool for APU knowledge engineering
VHM SENSOR DATA WITH CHANGING FREQUENCY AND ADDITIONAL GROUND NOISE
SAMPLED SPECTROGRAM DIFFERENCE

VHM SENSOR DATA WITH VARIATIONS IN FREQUENCY AND GROUND NOISE

POSITIVE SAMPLES

NEGATIVE SAMPLES
VHM SENSOR DATA WITH CHANGING FREQUENCY AND NOISE BUILDUP

TIME DOMAIN

SPECTROGRAM

TIME

FREQUENCY

LOGARITHM OF SPECTROGRAM

SPECTROGRAM DIFFERENCE

FREQUENCY

FREQUENCY
SAMPLED SPECTROGRAM DIFFERENCE

VHM SENSOR DATA WITH VARIATIONS IN FREQUENCY AND BUILDUP NOISE

POSITIVE SAMPLES

NEGATIVE SAMPLES
INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

TARGET HMS - STS / MPS FUEL FLOW