Health and Life Consumption Monitoring of Electronic Products

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IEEE 1413 and IEEE 1413.1

IEEE Standard Methodology for Reliability Prediction and Assessment for Electronic Systems and Equipment

Sponsor
Standards and Definitions Committee of the
IEEE Reliability Society

Approved 8 December 1999
IEEE-SA Standards Board

Abstract: The framework for the reliability prediction process for electronic systems and equipment, including hardware and software predictions at all levels, is covered.

Keywords: hardware prediction, reliability prediction, software prediction

IEEE Guide for Selecting and Using Reliability Predictions Based on IEEE 1413™

Sponsor
IEEE Standards Coordinating Committee 37
of Reliability Prediction

Approved 12 September 2002
IEEE-SA Standards Board

Abstract: A framework for reliability prediction procedures for electronic equipment at all levels is provided in this guide.

Keywords: baseline, classic reliability, constant failure rate, estimation, failure, goal, item, operating environment, reliability prediction, requirement, system life cycle
Findings: Reliability Prediction

- Mil-Hdbk-217, Bellcore, Prism and progeny handbook methods are flawed.
- Short-term testing and field data may not help us to extrapolate to longer-term applications unless there are good models.
- Stress and damage modeling has been successful. However, results are often not consistent with field data, because the application conditions are unknown.
How do we Deal with “Unknown” Application Conditions?

• Life cycle conditions
• Operation conditions
• Accidents
Life Consumption Monitoring
- Approach to Health Monitoring -

LCM is a method of monitoring parameters related to a system’s life cycle “health” and converting the measured data into life consumed. The “remaining life” of the product is the predicted reliability.
What is Health Monitoring?

- A product’s health is the extent of deviation or degradation from its expected normal operating condition.

- Normal operation: refers to the conditions (e.g., physical, performance) expected from the product.

- Knowledge of the extent of deviation or degradation from an expected normal operating condition (e.g. product’s health) can be used to assess (predict) the product’s reliability.
Health Monitoring Methods

• Monitor product environment (e.g., age, usage time, pollution, stress, temperature, temperature cycles, vibrations, humidity, radiation)

• Monitor performance degradation (e.g., shift of the product’s operating parameters from expected values)

• Monitor physical degradation (e.g., fractures, corrosion, delamination) or electrical degradation (increase in resistance, increase in threshold voltage)
Approaches for Health Monitoring

• **Diagnostic monitoring**: Monitor the current operating state of health to identify potential defects.

• **Prognostic monitoring**: Monitor of faults and predicting the time (number of cycles, etc) in which the fault may result in failure.

• **Life consumption monitoring**: Monitor operating and environmental conditions to predict the remaining life.
Challenges in Health Monitoring of Electronics versus Mechanical Systems

• Typical failures in many mechanical systems are due to wearout mechanisms (fatigue, creep, corrosion) that can be detected and prevented using periodic maintenance and replacement\(^1\).

• Wearout mechanisms in electronics are comparatively difficult to detect.
Challenges in Health Monitoring of Electronics versus Mechanical Systems (Cont’d)

- Defects in electronic devices may be in micron, sub-micron, or even nano-scale.

Electromigration induced failure of Al interconnect

Health Monitoring Methodology
(A Multi-Faceted Approach)
CALCE Health Monitoring Approach

Step 1: Conduct failure modes, mechanisms and effect analysis

Step 2: Conduct virtual reliability assessment to assess the dominant failure mechanisms and select the appropriate model and parameters to monitor

Step 3: Monitor appropriate product parameters
- environmental (e.g., shock, vibration, temperature, humidity)
- operational (e.g., voltage, power, heat dissipation)

Step 4: Conduct data processing and simplification to make sensor data compatible with stress and damage model requirements

Step 5: Perform stress and damage accumulation analysis

Step 6: Estimate the remaining life of the product

Is the remaining-life acceptable?

Yes → Continue monitoring

No → Schedule a maintenance or replacement action
Selecting the Parameters to be Monitored

• Determine monitoring parameters from Failure Modes, Mechanisms, and Effect Analysis (FMMEA)
  – Brainstorming using FMMEA techniques
  – Past experience (prior field failures and similar products)
  – Test data

• Identify parameters that
  – are crucial for safety
  – may cause catastrophic failure
  – Are essential for mission completeness
  – can result in long downtimes
Types of Data for Health Monitoring

- Operating conditions
  - Example; operating and non-operating time, usage frequency and severity, etc.

- Performance parameters
  - Example; voltage, resistance, power, speed, timing, pressure, etc.

- Defects and faults
  - Example; cracks, voids, wear debris, delamination, corrosion, voltage spikes, power surge, noise, etc.

- Life cycle environment
  - Example; temperature, humidity, radiation, vibration, shock, altitude, mishandling, electromagnetic pulses, acoustic noise, ozone, fuel spills, fungus, dog’s breath, Cicadas, etc.
Data Processing

• Determine how data is to be organized
  – e.g., what is needed and in what form

• Simplify the data for ease of analysis
  – e.g., conversion of vibration data from time domain to frequency domain, conversion of time-temperature data into cycles

• Process the data into information
  – e.g., data distributions, data trend analysis
Example
In-situ Temperature Monitoring of Laptop Computer

• Temperatures were monitored at three locations
  – Microprocessor heat-sink
  – Hard Disk Drive (HDD)
  – Atmospheric ambient (vicinity of the laptop)

• Laptop was continuously monitored in all stages including power on/off, operating and non-operating conditions, handling and travel.
Measured Temperature Data
Distribution of Absolute Temperature

Absolute Temperature Range (Celsius)

Percent Fraction of Total

Heatsink

HDD
Distribution of Cyclic Temperature Range

Time-temperature history is converted into equivalent cycles

Delta T (Celsius)

Number of Occurrences

- Heatsink
- HDD

<table>
<thead>
<tr>
<th>ΔT</th>
<th>Heatsink</th>
<th>HDD</th>
</tr>
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<tbody>
<tr>
<td>&lt; 5</td>
<td>937</td>
<td>739</td>
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<tr>
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<td>&gt; 50</td>
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Summary

- Use temperature history data and temperature changes from normal operation to assess the health of the laptop.
The SRMS is used to place satellites, space station equipment and other payloads in orbit. The first SRMS flew on the space shuttle mission STS-2 in November 1981.

Health monitoring, inspection, accelerated testing and physics-of-failure analysis showed that there was little degradation in the electronics and they could be expected to last another 20 years.
Remaining Life Assessment of Electronic Hardware: Space Shuttle Solid Rocket Booster

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United Space Alliance, Texas
Kennedy Space Flight Center, Florida
Marshall Flight Space Center, Alabama
CALCE EPSC, University of Maryland

Objectives
- Demonstrate simulation based remaining life assessment
- Provide inputs to assess viability of sustainment program
CALCE Research in Health Monitoring of Electronics Products
CALCE Health Monitoring History

- **2000**: Conducted mapping between sensor technologies and PoF analysis to assess practical real time life consumption monitoring of electronic systems.
- **2001**: Demonstrated the life consumption monitoring concept in an automotive application.
- **2002**: Studied in-situ semiconductor health monitors with fabricated cells for predicting remaining life due to semiconductor failure mechanisms including TDDB, hot carrier aging and electromigration.
  - Demonstrated the accuracy of life consumption monitoring process in predicting remaining life of a monitored electronic board.
- **2003**: Developed software modules to support environment and usage data collection that enables life consumption monitoring.
Diagnostic Monitoring
- Built-in-Test for Circuit Functionality -

• Built-in-Test (BIT) is an software-firmware diagnostic means to identify and locate faults and includes error detection and correction circuits, self-checking circuits, and self-verification circuits.

• In continuous BIT, the equipment is monitored continuously without affecting the normal operation.

• In interruptive BIT the normal equipment operation is suspended during BIT operation.
In-situ Semiconductor Health Monitors

- In-situ semiconductor health monitors are pre-calibrated cells (circuits) that are located with the actual circuitry on the same chip.
- Because of their location, these cells contain and experience substantially similar “dependencies” as that of the actual circuitry, but their stresses are accelerated by employing scaling methods.
- Selected failure mechanisms include dielectric breakdown, hot carriers, and electromigration.

![Graph showing failure probability density distributions for in-situ health monitors and actual circuitry over time.](image-url)
In-situ Semiconductor Health Monitors for Remaining Life Estimation

Failure of in-situ semiconductor health monitors with different acceleration factors

Failure of actual circuit

Prognostic distance for maintenance or logistics action
In-Situ Application Monitoring for Predicting Remaining Life  
- LCM Case Study -

Monitored environmental and operating conditions of test board  
Simplified data (e.g., data reduction, and cycle counting)  
Performed physics-of-failure based stress and damage assessment  
 Obtained the remaining life
Experimental Setup for Case Studies

3-D Piezoelectric accelerometer

Temperature sensor

Test board with 8 surface mount inductors
In-Situ Application Monitoring for Predicting Remaining Life

Estimated life based on similarity analysis (earlier CALCE case study) = 25 days

Estimated life based on SAE environmental handbook data with CALCE models = 34 days

Estimated life after 5 days of data collection (LCM = 46 days)

Estimated life after accident (LCM = 40 days)

Actual life from resistance monitoring = 39 days

Day of car Accident
Integrate the software into HUMS and evaluate the test board (to be used for HUMS validation) to obtain the time to failure and acceleration factors under thermal cycling.

Validate HUMS for predicting failures in thermal cycling and explore methods for vibration and shock assessment.

Study and calibrate in-situ “canary” (consumable) devices for supporting prognostic health monitoring.

Identify and assess the impact of input uncertainties on remaining life prediction using data from past CALCE projects.

Develop software for vibration and shock assessment and explore methods for humidity and contamination assessment.

Determine robustness levels for canary devices to indicate different degrees of exposure.

Develop a method for estimating the uncertainties in the remaining life prediction.

Assess the variability of canary devices in predicting remaining life and compare the accuracy levels with predictions obtained from using life consumption monitoring.

What is our ultimate goal?
## Our Goal

To develop an integrated hardware and software solution that can enable real time health and usage monitoring of electronic products in their application environment.

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Software</th>
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<tr>
<td>• Sensors</td>
<td>• HW–SW Interface</td>
</tr>
<tr>
<td>• Micro-processor and controller</td>
<td>• Data reduction algorithms</td>
</tr>
<tr>
<td>• Memory</td>
<td>• Cycle counting algorithms</td>
</tr>
<tr>
<td>• Power requirements</td>
<td>• Damage estimation models</td>
</tr>
<tr>
<td>• Packaging (size, weight)</td>
<td>• Damage accumulation models</td>
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<tr>
<td>• Networking</td>
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Health and Usage Monitoring System

- 2-axis accelerometer
- Temperature & RH sensor
- Microcontroller
- Terminals for data communication
- Terminals for battery
- Terminals for external sensors
- FRAM memory

HUMS - courtesy of EADS CCR
Summary

• Health monitoring is a promising approach because it assesses the actual conditions of a product.

• Health monitoring can be implemented using different methodologies, tools, and analyzing techniques.

• Next generation electronics will embed health and life consumption monitoring to ensure reliable application life.
References


