CALCE conducted a two-day technical review meeting for the PHM Consortium on March 20-21, 2012, at the University of Maryland, College Park. During this meeting, the CALCE PHM Group presented their latest research efforts on innovative PHM methodologies and implementations for consortium members, including Schlumberger, Boeing, GM, Dell, US CECOM, and others. The projects presented at the meeting include:

**BATTERIES**

- **SOC and SOH Dependence in Lithium-ion Battery State Estimation**, which presented a generalized approach for combining state of charge (SOC) and state of health (SOH) techniques together to create a self-adaptive battery monitoring system. The proposed method is able to utilize SOH predictions to update the SOC estimator in order to minimize modeling errors due to capacity loss and cell degradation.

- **State of Charge Estimation for Electric Vehicle Batteries under an Adaptive Filtering Framework**, which presented an Unscented Kalman filtering-based approach to perform SOC estimation under dynamic loading conditions. The proposed approach is able to self-adjust the battery model parameters and provide the SOC estimation with a known level of confidence.

- **Implementation of State of Charge Estimation for Lithium-ion Battery Balancing**, which presented a state-of-charge estimation-based method to investigate the effect of cell imbalance on battery capacity fade. The proposed method is able to detect cell imbalance more accurately and keep all the cells operating within safety limits.

**BEARINGS**

- **Early Detection of Fan Bearing Faults using Acoustic Emission Signals**, which presented the use of the sequential probability ratio test for the detection of statistical changes against a null hypothesis/healthy data at the earliest possible time. The proposed method is able to extract features in a statistical way from sensor signals that are indicative of and sensitive to bearing degradation.

- **Fault Simulation and Diagnostics using System-Level Signals by Dynamic Modeling**, which presented the use of system-level signals to perform component-level diagnosis. The proposed method is able to detect and identify component-level faults in a complex system, such as a wind turbine, with a greatly reduced number of monitoring sensors.

- **Diagnosis of Rolling Element Bearing Fault in Bearing-Gearbox Union System using Wavelet Packet Correlation Analysis**, which presented a novel feature extraction method based on wavelet packet transform, correlation analysis, and envelope analysis. The proposed method is able to extract fault features of the rolling element bearing from the masking faulty gearbox signals.
CALCE PHM SPRING TECHNICAL REVIEW

ANALOG CIRCUITS

• PHM Framework for the Real-Time Assessment of Analog Circuits, which presented a systematic approach to perform online soft-fault diagnosis and prognosis on actual analog circuits subjected to component variations within a standard tolerance range. The proposed approach is capable of detecting and isolating faults, and predicting circuit failure in real-time, and thus, can be used to evaluate the reliability of electronic systems during field operation.

SOFTWARE

• PHM Software Suite, which presented a generic, modular, flexible, and interoperable software architecture that effectively and efficiently integrates various PHM routines. The proposed software can be implemented on-board and in real-time with easy deployment and maintenance/update.

IGBTs

• Degradation Mechanisms of Inductively Loaded Field-Stop Trench-Gate Insulated Gate Bipolar Transistors under Power Cycling, which presented a study of the degradation of FS-TIGBTs under inductive load with different switching frequencies, duty cycles, and temperature swings. The study is able to identify the effects of different loading conditions on different failure mechanisms of FS-TIGBTs through multiple failure analyses, including cross-sectioning, scanning acoustic microscopy (SAM), scanning electron microscopy (SEM), and others.

• Anomaly Detection for IGBT under Power Cycling using Statistical Approach, which presented the use of statistical methods, including Principal Component Analysis (PCA) and a modified K-Nearest Neighbor technique, to detect the anomalies of IGBTs in real-time.

LEDs

• Prognostics and Health Management of High Power Light Emitting Diodes (LEDs), which presented a data-driven method incorporating similarity-based statistical measures to estimate the remaining useful life of LEDs. The proposed method is able to predict the remaining useful life of LEDs with unit-to-unit variations using multiple health indicators that can be directly obtained from measurements.

WARRANTIES

• A Novel Warranty Servicing Approach based on Prognostics, which presented the use of PHM methods as a proactive means to improve business warranties, in terms of identifying no-fault-found failures, understanding root causes of failures, alleviating problems associated with recalls, enabling optimized warranty service and logistics decisions, and creating new warranty strategies.

• Lifetime Warranty Policies for Electronic Products, which modeled the lifetime of electronic products as a function. The proposed method is able to devise an implementable lifetime warranty policy for electronic products and develop the associated cost models.

STANDARDS

• IEEE Standard for PHM, which is beneficial to those who wish to implement prognostics for complex systems through the development of an IEEE standard for PHM.

The Prognostics and Health Management Consortium (PHMC) is an industry and government supported research and education consortium within the Center for Advanced Life Cycle Engineering (CALCE). The mission of the PHM Consortium is to provide advanced research and technology on prognostics and health management to members. CALCE has been performing cooperative, industry-focused research on PHM for more than 10 years with a demonstrated track record of disseminating research results for industrial competitive advantage. CALCE's interdisciplinary PHM Consortium team consists of faculty in mathematics, computer science, electronics, reliability, materials, and civil and mechanical engineering. The resources available to the PHM Consortium include the CALCE testing and failure analysis laboratory (TSFA), one of the largest and most extensively equipped electronics failure analysis facilities in the world, access to and use of University of Maryland CALCE Materials under the CALCE PHMC Web Site, and proprietary CALCE-developed virtual qualification software for electronic products. For more details on the meeting and PHMC, please contact Dr. Chaochao Chen (chaochao@umd.edu)
ANOMALY DETECTION FOR INSULATED GATE BIPOLAR TRANSISTORS (IGBTs) UNDER POWER CYCLING USING STATISTICAL ANALYSIS

An Insulated Gate Bipolar Transistor (IGBT) is a power electronic device used in medium to high power applications such as hybrid cars, railway traction motors, switch mode power supplies, and wind turbines. The global market for IGBTs has experienced tremendous growth in recent years, driven by the automotive industry, alternative energy, and the demand for power-efficient systems. Despite the advancement in IGBT design for reliability, failures still continue to occur in the field. As IGBTs find their ways into large and complex systems, the costs of unexpected failure, unscheduled maintenance, and loss of availability can become a major operational issue. The ability to detect the onset of failure in IGBTs will provide valuable information for operators in scheduling maintenance and avoiding unexpected costs.

The research in IGBT prognostics at CALCE is focused on developing an algorithm that can predict failures in an IGBT by analyzing data collected from the IGBT’s operating parameters. An anomaly detection algorithm is developed using data collected from experimental aging of IGBT samples. By understanding the dominant failure mechanism and degradation mode of IGBTs, we identify several key features extracted from the operating parameters. The algorithm performs a reduction of variable dependency using Principal Component Analysis (PCA) and a classification using a distance-based K-Nearest Neighbor (KNN) technique. The anomaly detection algorithm is summarized as the following flowchart.

For more information, please contact Dr. Chaochao Chen (chaochao@umd.edu).
LEDs have been considered a significant alternative light source due to, among other things, their high energy efficiency resulting in low power consumption, wide range of color options, and lack of low-temperature startup problems.

To assess the reliability of LEDs, manufacturers usually perform tests using industrial standards such as JEDEC or JEITA (there is no industry-wide standard for LEDs). Use of standards based qualification without consideration of actual LED failure mechanisms results in testing without value, since there is no relationship provided to relate time under accelerated test conditions, to time under field conditions.

The goal of this project is to develop a data-driven based PHM framework for fault detection and remaining useful life (RUL) prediction of LEDs by utilizing two different measurement streams (i.e., in-situ monitoring and lab-based spectral power distribution data).

For more information, please contact Dr. Diganta Das (digudas@calce.umd.edu).

RECENT CALCE PAPERS ON PHM

USING CROSS-VALIDATION FOR MODEL PARAMETER SELECTION OF SEQUENTIAL PROBABILITY RATIO TEST


The sequential probability ratio test is widely used in in-situ monitoring, anomaly detection, and decision making for electronics, structures, and process controls. However, because model parameters for this method, such as the system disturbance magnitudes, and false and missed alarm probabilities, are selected by users primarily based on experience, the actual false and missed alarm probabilities are typically higher than the requirements of the users. This paper presents a systematic method to select model parameters for the sequential probability ratio test by using a cross-validation technique. The presented method can improve the accuracy of the sequential probability ratio test by reducing the false and missed alarm probabilities caused by improper model parameters. A case study of anomaly detection of resettable fuses is used to demonstrate the application of a cross validation method to select model parameters for the sequential probability ratio test.

REMAINING USEFUL LIFE ESTIMATION BASED ON A NONLINEAR DIFFUSION DEGRADATION PROCESS


Remaining useful life estimation is central to the prognostics and health management of systems, particularly for safety-critical systems and systems that are very expensive. We present a non-linear model to estimate the remaining useful life of a system based on monitored degradation signals. A diffusion process with a nonlinear drift coefficient with a constant threshold was transformed to a linear model with a variable threshold to characterize the dynamics and nonlinearity of the degradation process. This new diffusion process contrasts sharply with existing models that use a linear drift, and also with models that use a linear drift based on transformed data that were originally nonlinear. Both existing models are based on a constant threshold. To estimate the remaining useful life, an analytical approximation to the distribution of the first hitting time of the diffusion process crossing a threshold level is obtained in a closed form by a time-space transformation under a mild assumption. The unknown parameters in the established model are estimated using the maximum likelihood estimation approach, and goodness of fit measures are applied. The usefulness of the proposed model is demonstrated by several real-world examples. The results reveal that considering nonlinearity in the degradation process can significantly improve the accuracy of remaining useful life estimation.
The Hong Kong Productivity Council and PHM Centre, City University of Hong Kong, will co-organize this conference at Golden Central Hotel, Shenzhen, China, on May 21st, 2012. The conference will address challenges in battery management systems (BMSs) from the fundamental engineering and chemistry perspectives and focus on finding innovative approaches to achieve BMSs’ high operational availability and safety. It will review the recent research and development of BMSs, discuss prognostics and health monitoring for a variety of battery chemistries, and summarize the techniques, algorithms, and models used for state of charge (SOC) estimation, state of health (SOH) estimation, state of life (SOL) estimation, and remaining useful life (RUL) prediction. This conference will also focus on battery safety issues and how prognostic methodologies can be applied to BMSs in order to improve the system performance. Other BMS functions, such as maintaining safe operational voltage and current levels, performing cell balancing, and controlling active heating and cooling functions, will be described. Future possible improvements of BMS technologies will also be discussed.

The CALCE Battery Group and their collaborators at the City University of Hong Kong will present the most recent advancements of BMSs in terms of availability and safety. The presentations include:

- Dr. Eden Ma (City University of Hong Kong): Battery’s Trends and Challenges
- Dr. Chaochao Chen (CALCE): Battery Management Systems
- Mr. Wei He (CALCE): Battery Safety Requirements and Approaches
- Mr. Nick Williard (CALCE): Battery Chemistries and Degradation Mechanisms
- Ms. Laura Xing (City University of Hong Kong): Battery State of Charge, State of Health and Remaining Useful Performance Analysis

The MFPT 2012 Conference will be held April 24-26, 2012, at the Crowne Plaza Hotel in Dayton, OH. The conference will focus on the development and application of prognostics and health management technologies and show how practical technologies can be integrated into platforms and systems. For more information, visit http://www.mfpt.org/MFPT2012/CallforPapers.htm.
IEEE PHM CONFERENCE IN CHINA

The 2012 Prognostics and System Health Management Conference (PHM-2012) will be held in Beijing, China, on May 23-25, 2012, following the success of the PHM-2010 Macau and PHM-2011 Shenzhen conferences. The PHM-2012 conference aims to bring together the global community of PHM experts from industry, academia, and government in diverse research and application areas such as aeronautics and astronautics, defense, marine systems, power and electronic systems, process industries, computers and telecommunications, material systems, industrial automation, and healthcare and medical technology. For more information, please visit: http://www.icphm.org.

The CALCE PHM Group will present some of the ongoing research projects at the conference:
- Dr. Chaochao Chen: Prognostics of Lithium-ion Batteries using Model-based and Data-driven Methods
- Mr. Wei He: State of Charge Estimation for Electric Vehicle Batteries using Adaptive Filtering
- Ms. Preeti Chauhan: Use of Temperature as a Health Monitoring Tool for Solder Interconnect Degradation in Electronics

Two tutorials will be given by CALCE researchers on May 23th:
- Dr. Chaochao Chen: Prognostics and Health Management Fundamentals
- Mr. Nick Williard: Advancing Battery Management Systems through PHM Methodologies

2012 IEEE INTERNATIONAL CONFERENCE ON PHM

The IEEE Reliability Society is proud to sponsor its third annual International Conference on Prognostics and Health Management (IEEE PHM 2012). The conference will be held on June 18-21, 2012 at the Omni Interlocken Resort in Denver, Colorado. The 2012 IEEE PHM Conference is bringing together the expertise of relevant technical and management communities to facilitate cross-fertilization in this broad interdisciplinary technical area. For more details, visit http://www.phmconf.org.

ANNUAL CONFERENCE OF THE PHM SOCIETY 2012

The Annual Conference of the Prognostics and Health Management Society 2012 will be held at the Hyatt Regency in Minneapolis, Minnesota on September 23-27, 2012. The conference will bring together the global community of PHM experts from industry, academia, and government in diverse application areas such as energy, aerospace, transportation, automotive, and industrial automation. For more information, visit: http://www.phmsociety.org/events/conference/phm/12.

JOIN THE CALCE PHM CONSORTIUM

If you are not a member and would like to join the CALCE Prognostics and Health Management Consortium, please email Dr. Chaochao Chen (chaochao@umd.edu), and we will provide you with the membership agreement. Upon becoming a member, you will have membership benefits in terms of access to PHMC materials, research projects, education, and cooperative programs.