NSF Award for Battery Prognostics and Health Management

The Center for Advanced Life Cycle Engineering (CALCE) has received a three-year NSF grant to develop prognostics and health management strategies for battery management systems to improve the safety and reliability of battery-powered systems, including portable electronics devices, electrical vehicles, and other applications.

With increasing concerns about global warming and fossil fuel depletion, electric vehicles (EVs) are penetrating the automobile market. However, they face criticism related to battery performance. One problem is “range anxiety” — the fear of running out of battery power, which has been recently validated by Nissan Leaf drivers who were left stranded on the road due to inaccurate prediction of the end-of-discharge (EOD), which is the time at which a battery runs out of electrical charge. Another issue is the safety of the battery pack, which can rupture, ignite, or even explode under certain conditions. For example, a hybrid Toyota Prius EV was destroyed by a battery fire in 2008, and a Chevy Volt battery caught fire three weeks after a National Highway Traffic Safety Administration (NHTSA) crash safety test in 2011. Therefore, a prognostic method is required that can predict EV batteries’ remaining-useful-performance (RUP) in real time. RUP refers to a prediction of the time when the battery will fail to deliver the required level of performance. As a result of RUP prediction, timely maintenance can be carried out to prevent catastrophic failures. CALCE will develop new prognostic methods that predict battery EOD and RUP with a known level of confidence to ensure the operational readiness and safety of battery-powered systems, including EVs. Our approach involves online sensing, physics modeling, machine learning algorithms, and fusion technology to address battery state and health prediction considering various prognostic uncertainties.

Existing prognostic algorithms for batteries lack the ability to predict the EOD and RUP of batteries under dynamic loading conditions. They often fail to provide correct predictions due to neglect of unit-to-unit variability, modeling errors, noise, and loading condition changes. CALCE will make the first attempt to predict battery future loading conditions through continuous-time statistical nonlinear filtering. The time evolutions of the loading conditions will be modeled using stochastic differential equations as fluctuating processes. Modeling the battery dynamics by investigating the intercalation strain on battery electrodes and employing machine learning techniques are novel aspects of the proposed effort. In addition, this work will combine physics-based and data-driven-based models under an online fusion prognostic framework to provide robust prediction with a known level of confidence.

This research will improve the operational readiness and safety of battery-powered systems that are used in applications ranging from commercial (electric vehicles) to defense (unmanned aerial vehicles) sectors. In 2011, President Obama announced his goal of having one million electric vehicles on the road by 2015. The proposed research will make significant contributions to reaching this target, since it could help to ease user concern about the safety and reliability of electric vehicles by providing robust battery state and health information in real-time, thus encouraging their widespread use. For further information of battery work at CALCE, please contact Prof. Michael Pecht (pecht@calce.umd.edu).
CALCE Battery Collaboration and Facilities

The CALCE battery team has been developing smart battery management systems (BMSs) to ensure the safety and reliability of various battery-powered systems, such as portable electronics and electrical vehicles. The team has addressed battery safety and reliability problems by investigating battery physics modeling, prognostics, online sensing, cell balance, and optimal control.

The CALCE battery team has multiple collaborators in academia and industry. Within the University of Maryland, the Department of Chemical and Biomolecular Engineering focuses on fundamental electrochemistry, materials synthesis, and electrochemical devices. CALCE is in collaboration with the Chemistry Department at the City University of Hong Kong to investigate fault seeding in lithium ion batteries by incorporating seeded faults into coin cell designs and then using electrochemical impedance spectroscopy to evaluate how these batteries respond differently to charge-discharge cycling. These tests are enhancing the understanding of how different degradation mechanisms can be recognized through the analysis of impedance data. Additionally, this work is paving the way for a radically new method of accelerated testing for batteries. With this testing, we will be able to determine the effects of individual failure mechanisms by incorporating specific seeded faults.

CALCE has formed a research partnership with Ming Chi University of Technology in Taiwan to understand the electrical responses of a battery during “high risk” situations, including internal short circuits, extreme external temperature conditions, and overcharge and overdischarge conditions, to provide warnings of impending safety hazards such as fires or explosions. Incorporating the “high risk” failure warnings into battery management systems can significantly enhance the safety of battery-powered systems. Among CALCE’s partners in industry, MicroStrain is developing advanced online sensing technology, Oracle performs failure analysis, and RIM performs reliability analysis on aftermarket batteries. L-3 Communications will assist CALCE in the application of prognostics and health management techniques.

CALCE’s Failure Analysis and Materials Characterization Laboratory has state-of-the-art battery testing equipment. CALCE has commercial battery testers that allow for customizable charge and discharge profiles. By employing environmental chambers and vibration tables for simulating usage environments, these battery test systems are being used in conjunction with data acquisition systems for collecting auxiliary data. CALCE also has equipment for optical, X-ray, and scanning electron microscopy, an energy dispersive spectroscope, and microsectioning equipment for performing root cause analysis on failed batteries to determine the physical causes of failure. In addition, CALCE has access to facilities at the University of Maryland for electrode material synthesis, cell fabrication, and electrochemical impedance spectroscopy.

CALCE Recent Publications, Tutorials, Short Courses, and Presentations

Referred Journal Publications, 2011-2012:


Conference Publications, 2011-2012:

• C. Chen and M. Pecht, Prognostics of Lithium-Ion Batteries Using Model-Based and Data-Driven Methods, *2012 Prognostics & System Health Management Conference (PHM-2012 Beijing)*, 2012.


• N. Williard, Improved SOH Estimation through Coulomb Counting, *BMS workshop PHM Society Conference*, September 2011, Montreal, Quebec.


**Tutorials and Short Courses, 2011-2012:**


Presentations, 2011-2012:


- M. Pecht, Battery Management System—Advances in Prognostics, Taiwan NSF Forum, Taipei, TW, April 18, 2012.


**CALCE Student Receives 2nd L-3 Fellowship For Battery Research**

L-3 Communications in 2011 awarded the L-3 Fellowship to Nick Williard (and his adviser, Prof. Pecht) to study prognostics and health management, cycle life testing, and failure analysis of lithium-ion batteries. In September 2012, Mr. Williard’s fellowship was renewed for a second year. The fellowship has enabled a strong connection between CALCE and L-3 Communications for the exchange of knowledge and collaboration between both establishments.

Mr. Williard’s research has focused on identifying and modeling mechanisms that cause batteries to lose capacity and power. These are performed by inserting faults directly into batteries to analyze their behavior. For example, faults can be generated by leaving the battery materials exposed to the external air so that a surface layer would form on the lithium electrode; by putting less binder material into the cathode; by bending the cathode; and by thermal aging the battery after assembly but before cycling testing. CALCE is designing methods to seed faults that simulate known failure mechanisms into batteries. When cycling a battery, multiple degradation mechanisms are compounded, making it difficult to understand how each mechanism individually influences performance. By designing and controlling these faults, each failure mechanism can be studied. This testing also provides a method of performing accelerated testing to enable more timely qualification and screening of batteries.

**CALCE Research—Battery State of Charge Estimation and State of Health Prediction**

State of charge (SOC) estimation is critical for battery-powered systems, because it indicates when batteries need to be recharged and provides information to battery management systems to prevent the over-charge and over-discharge of batteries. However, SOC estimation is a challenging problem, because various factors can affect it, such as temperature, discharge rate, battery ageing, and self-discharge. In addition, different battery materials possess different charge-discharge characteristics. There is no universal battery model for SOC estimation. To address this need, CALCE is developing battery SOC models based on data-driven and physics-based methods. The models will be automatically tuned based on the training data collected from battery discharge tests. To improve the estimation accuracy, nonlinear filtering techniques, such as the unscented Kalman filter, will be used to reduce the noise in the SOC output of battery models.

Failure of a battery can lead to loss of operation, reduced capability, downtime, and even catastrophic failure. In order to address this problem, CALCE is developing advanced state of health (SOH) estimation and prediction methods. The online measured battery parameters, such as the current, voltage, and resistance, will be transformed to the SOH of batteries. Physics modeling, machine learning, and statistic methods will be used to capture the degradation trend of a battery and predict the SOH. With the prediction of SOH in place, predictive maintenance can be conducted to ensure the availability of battery-powered systems.
Short Course on Battery Management

Monday, November 5, 2012
Venue: University of Maryland
College Park, MD 20742

Course Description
Renewable energy sources, such as solar, wind, and tidal energy, are intermittent, which makes them unsuitable for applications demanding a constant use of energy. In order to enable the penetration of renewable forms of energy, efficient energy storage systems such as batteries are required. Portable electronics, electric vehicles, and energy storage systems for renewable energy sources all rely on the operational availability of batteries. An intensive one-day battery course on battery management is being offered by the Center for Advanced Life Cycle Engineering (CALCE), at the University of Maryland, College Park. The course covers battery fundamentals, including operation, materials, and chemistry. The course will present the issues of battery safety and reliability and how they can be actively governed by an autonomous battery management system. It covers battery failure mechanisms and analysis, which includes step-by-step demonstrations of battery monitoring and failure analysis using CALCE’s state-of-the-art testing and failure analysis equipment. It will introduce the methods of battery health monitoring and failure prognostics, followed by a discussion of how to choose a battery supplier and future trends of batteries.

Benefits
This course will help attendees to:
• Understand what types of batteries to choose for specific applications.
• Understand why and how a battery can fail under certain conditions.
• Learn methods to estimate how long a battery can operate before it needs to be recharged and how many operational cycles a battery can undergo before it should be replaced.
• Understand how to perform fundamental battery monitoring and failure analysis.
• Share ideas and experiences with peers from academy and industry.

Presenters
The presenters will include battery experts from CALCE and the Department of Chemical and Biomolecular Engineering within the University of Maryland who are involved in the chemistry, packaging, safety, reliability, failure testing and analysis, health monitoring and prognostics assessment of batteries.

Course Outline
• Battery Operation, Materials, and Chemistry
• Safety and Reliability—Failure and Degradation Mechanisms
• Introduction to Health Monitoring and Prognostics of Batteries
• Battery Management Systems
• Battery Testing and Failure Analysis—Lecture and Lab Demo
• Selecting a Battery Supplier
• Future Trends

8 a.m.—breakfast and registration
Class time—8:30 a.m. - 5:10 p.m.

For detailed information on the short course and for registration, please contact Chaochao Chen at chaochao@umd.edu or 301-405-5331.
2013 IEEE Aerospace Conference, Big Sky, Montana, March 2-9, 2013

The 2013 IEEE Aerospace Conference (www.aeroconf.org/) is the 34th in a series of annual week-long conferences designed for aerospace experts from industry, government, and academia in a stimulating and thought-provoking environment. The conference promotes interdisciplinary understanding of aerospace systems, their underlying science and technology, and their applications to government and commercial endeavors. Technical cosponsors include AIAA and the PHM Society. Dr. Chaochao Chen of CALCE will chair the session 11.02 Prognostics for Electronics and Avionic Systems. Interested researchers are welcome to submit their work to this session. For further information, please contact Dr. Chen at chaochao@umd.edu

4th IEEE International Conference on Prognostics and Health Management

The 2013 Prognostics and System Health Management Conference, PHM-2013, will be held on September 8-11, 2013, in Milan, Italy. As many efforts are being devoted to the development of techniques for health monitoring, fault detection, diagnosis, and prognosis with the intent of improving the safety and economic performances of existing and future structures, systems, and components, this Conference aims at exchanging knowledge on the state-of-the-art in Prognostics and System Health Management (PHM) research and application. Presentations on developments in various industrial fields are expected to highlight differences in research challenges and practical needs. The event is being organized by AIDIC, the Italian Association of Chemical Engineering. Details on the conference and the call for paper may be found at www.aidic.it/phm. The first deadline for abstract submission is: October 23, 2012.

MFPT 2013: Sensors and Systems for Reliability, Safety and Affordability

A Joint Conference—MFPT 2013 and ISA’s 59th International Instrumentation Symposium—will be held on May 13-17, 2013, in Cleveland, Ohio. The MFPT section of the Conference will focus on the development and application of prognostics and health management technologies, and will show how practical technologies can be integrated into a platform or system. MFPT headquarters is now accepting titles for proposed papers or tutorials with accompanying abstracts. Submissions are encouraged from academia, government entities and industry. Please submit an abstract (500 words max) for your proposed paper or tutorial on the MFPT website by Monday, October 1, 2012, using the MFPT 2013 Abstract Submission Form. For detailed information, please visit www.mfpt.org/MFPT2013/CallforPapers.htm

International Workshop on Structural Health Monitoring 2013

The International Workshop on Structural Health Monitoring 2013 (IWSHM) will be held September 10-12, 2013, at Stanford University in Stanford, California. The purpose of the workshop is to assess the current state-of-the-art technologies in this field and discuss key and emerging issues in research and development that are critical and unique in structural health monitoring. The workshop is also intended to promote communication exchange and cross-fertilization between multiple disciplines. Technical presentations will be made by invited and selected distinguished speakers, and plenary discussions on the future direction and a “road-map” will be held. Potential applications of the techniques to military and civilian structures will be discussed. An exhibition area will be available for product and technology demonstrations. To submit a paper for consideration, please send a succinct one-page abstract that clearly describes the contents of the proposed paper. Online abstract submission starts on October 15, 2012. For detailed information, please visit http://structure.stanford.edu/workshop.

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@calce.umd.edu). We will provide you with the membership agreement. Upon becoming a member, you will have membership benefits including access to PHMC materials, research projects, education, and cooperative programs.