Mechanical Engineering Doctoral Defense

Health Management of Complex Systems Integrating Multisource Sensing, Nondestructive Evaluation, and Machine Learning

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Abstract

Structural/system health monitoring (SHM) and prognostic health management (PHM) are vital techniques to ensure engineering system reliability and safety during the service. As multi-functionality and enhanced performance are in demand, modern engineering systems including aerospace, mechanical, and civil applications have become more complex. The constituent and architectural complexity, and multisource sensing sources in modern engineering systems may limit the monitoring capabilities of conventional approaches and require more advanced SHM/PHM techniques. Therefore, a hybrid methodology that incorporates information fusion, nondestructive evaluation (NDE), machine learning (ML), and statistical analysis is needed for more effective damage diagnosis/prognosis and system safety management.

This dissertation presents an automated aviation health management technique to enable proactive safety management for both aircraft and national airspace system (NAS). A real-time, data-driven aircraft safety monitoring technique using ML models and statistical models is developed to enable an early-stage upset detection capability, which can improve pilot's situational awareness and provide a sufficient safety margin. The detection accuracy and computational efficiency of the developed monitoring techniques is validated using commercial unlabeled flight data recorder (FDR) and reported accident FDR dataset. A stochastic post-upset prediction framework is developed using a high-fidelity flight dynamics model to predict the post-impacts in both aircraft and air traffic system. Stall upset scenarios that are most likely occurred during loss of control in-flight (LOC-I) operation are investigated, and stochastic flight envelopes and risk region are predicted to quantify their severities.

In addition, a robust, automatic damage diagnosis technique using ultrasonic Lamb waves and ML models is developed to effectively detect and classify fatigue damage modes in composite structures. The dispersion and propagation characteristics of the Lamb waves in a composite plate are investigated. A deep autoencoder-based diagnosis technique is proposed to detect fatigue damage using anomaly detection approach and automatically extract damage sensitive features from the waves. The patterns in the features are then further analyzed using outlier detection approach to classify the fatigue damage modes. The developed diagnosis technique is validated through an in-situ fatigue tests with periodic active sensing.

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