ABSTRACT

DATA INTERPRETATION FRAMEWORKS EMPLOYING MACHINE LEARNING FOR ENERGY-LEAN DATA-DRIVEN STRUCTURAL HEALTH MONITORING WITH NOVEL SELF-POWERED SENSING TECHNOLOGY

By

Hadi Salehi

Advisor: Dr. Rigoberto Burgueño

Recent advances in energy harvesting technologies have led to the evolution of self-powered structural health monitoring (SHM) techniques that are energy-lean. Concurrent to the emergence of self-powered sensing has been the development of power-efficient data communication protocols. The pulse switching architecture is among such protocols employing ultrasonic pulses for event reporting and transmitting binary data/signals through the substrate material. The uniqueness of the through-substrate self-powering is that the energy required for data computational, storage, and transmission is directly harvested from the signal being sensed as well as from ambient vibrations, thus providing a promising alternative to traditional sensor systems. However, a system using such self-powered sensing technology demands dealing with power budgets for sensing and communication of binary data, resulting in missing and incomplete data received at the SHM processor due to unique time delay constraint. The nature of data thus imply the necessity for development of new data mining frameworks. This research addresses the noted
issue through the development of advanced data interpretation frameworks to interpret asynchronous discrete binary time-delayed and incomplete/missing data for energy-lean SHM of plate-like structures. Finite element simulations on an aircraft stabilizer wing and structural plates were conducted to validate the proposed methodology. Further, experimental vibration tests on dynamically loaded plates were carried out to demonstrate the applicability of the approach on a realistic structure.

The proposed data interpretation frameworks for data-driven SHM with discrete time-delayed binary and incomplete (sparse) data were established based on the integration of machine learning, pattern recognition, a data fusion model, probabilistic, and statistical approaches. First, it was assumed that the SHM system operates with full data availability and the constraints of the communication power budget for the sensors and the time delay were not considered. On this basis, a pattern recognition-based algorithmic framework merging an image-based pattern recognition approach using anomaly detection, statistical measures, and numerous machine learning classifiers were developed for self-powered damage identification with full discrete binary data. In addition, the robustness of the developed pattern recognition framework with respect to different levels of damage severity, irregular loading condition, and sensor sparsity was evaluated. An uncertainty analysis was also conducted to ascertain the effectiveness of the data mining framework with noise contaminated data. In the next analysis phase, the effect of time delay due to the pulse switching communication architecture was taken into account and algorithmic frameworks detecting effect of delay were pursued. In this context, probabilistic approaches were developed to model and predict delay, whereas damage was classified through different machine learning algorithms. Further, novel machine learning-based data interpretation frameworks that incorporate low-rank matrix completion, an image-based pattern recognition approach, a data fusion model, machine
learning algorithms, and a statistical approach was developed to reconstruct/recover incomplete (sparse/delayed) data and to identify damage with reconstructed/imputed incomplete/missing data. The effectiveness and robustness of the developed machine learning-based data interpretation frameworks with respect to harvested energy variations were evaluated. Numerical and experimental results demonstrate that the proposed energy-lean data-driven SHM methodology using machine learning is efficient for detecting damage from a self-powered sensing technology.