Structural Health Monitoring using a Drone Delivered Sensor Package

Joud Satme, Electrical Engineering; Dr. Austin Downey, Mechanical Engineering
University of South Carolina

Project Goals and Objectives:

The objective of this project is to design, fabricate, and test a fully automated and low-cost sensor package that will record the structure's vibration signature. A structure's vibrational signature contains crucial information about a structure's health state. Utilizing compact, low power sensor packages will enable mass deployment of those sensors onto and around the structures in question for extended periods, providing a higher accuracy of damage detection and localization.

Project Goals and Objectives:

Utilizing unmanned aerial vehicles, sensor packages can be delivered to remote and inaccessible structures such as railroad bridges and high voltage electrical transmission towers. Multiple packages can be potentially mounted onto one mother drone with the aid of electro permanent magnets. A harness system is developed to ensure the package remain secure during flight and assist in retrieving the package onto the docking pad. The docking sequence consists of 4 stages. The UAV approach's structure, ensures package contact with a ferrous surface, toggles electro permanent magnets, and finally disengages. During retrieval, the docking sequence is reversed, and the package is secured in the harness to be brought back.

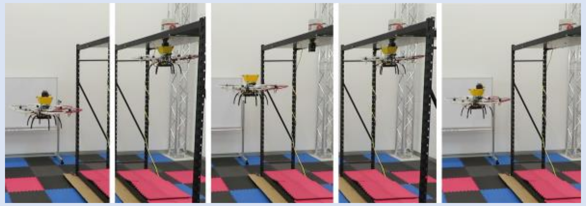

Figure 1: UAV sensor package deployment and retrieval utilizing the harness system.

Background:

Infrastructure, including bridges, utility poles, and overhead roadway signage, can suffer damage due to extreme weather events such as hurricanes, tornados, or floods. Moreover, as extreme weather events are becoming more frequent and our infrastructure continues to age, severe damage to infrastructure will become more common. Following extreme weather events, it is necessary to rapidly inspect infrastructure for damage, however, traditional inspection methods are human-intensive and may threaten the safety of emergency crews if the state of the structure is unsafe or unknown.

To accelerate the inspection of infrastructure after significant weather events, it is proposed to use unmanned aerial vehicles to deploy self-contained sensor packages. These packages would include sensors, memory, and an independent power supply capable of powering the sensor package from several hours to days. Moreover, an electropermanent magnet will be used for mounting the sensor package unto steel structures. The ability to carry relatively high loads and the maneuverability of drones will be utilized to gain access to structures in hard to reach or remote locations that may be inaccessible or dangerous for human inspectors. Using drone aircraft significantly cuts down on the time needed to acquire data, in addition to the ability to monitor multiple structures using multiple sensor packages deployed by one Mother-Drone. The rapid structural assessment of infrastructure components is crucial, as the quicker, the data is collected and processed, the faster early responders can get to the issue and fix it before further damage or losses.

Sensor package design:

The goal in this work is to design a low-cost sensor package that can be deployed by a drone and collect sufficient vibration data. Features include a docking system utilizing a low power electropermanent magnet in addition to wireless control and data retrieval capabilities. A compact 3D printed frame is designed to house the electronics and the onboard battery during flights and long-term sustained testing. The package's processing core consists of an ARM Cortex-M7 processor onboard the Teensy 4.0 high performance microcontroller. The sensor package utilizes the 600 MHz clock speed of the Teensy 4.0 and SPI (Serial Peripheral Interface) to communicate between the modules to achieve a data collection rate up to 28kHz. Power is supplied using a DC-DC buck converter (MP1584EN manufactured by Monolithic Power Systems) and a lithium polymer battery (Lumenier 7.4V 1000mAh). The docking system consists of an electropermanent magnet (NicaDrone EPM V3 R5C) for mounting the sensor package onto metal surfaces. The package collects acceleration data using a MEMS accelerometer (Murata SCA3300-d01) mounted to the metal frame of the electropermanent magnet to ensure contact with the structure being examined.

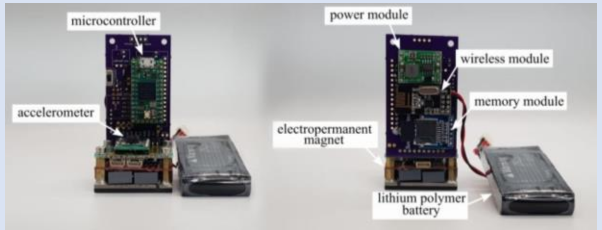

Figure 2: Sensor package circuit with key components annotated.

Structural health monitoring Tests:

This test was to validate the ability of the sensor package to collect data for SHM, data was collected from the structure under a variety of conditions utilizing the experimental setup shown in **figure 3**. Since the system is designed to detect Level 1 damage, the sensor package is used to collect data before and after the structure has sustained damage. To simulate structural deterioration, three bolts supporting the steel plate are removed.

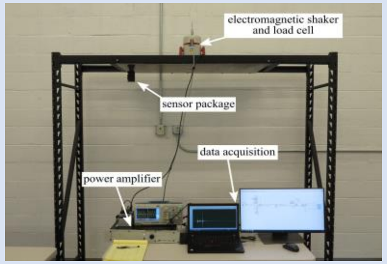

Figure 3: Experimental setup of an SHM test.

An undamaged structure will exhibit the same free vibration response with high correlation between trials if excited at the same frequency. In **figure 4** the same test is conducted after damaging the structure. As the results indicate, the structure's free vibration response experienced a very low level of correlation indicating that the structure has suffered damage.

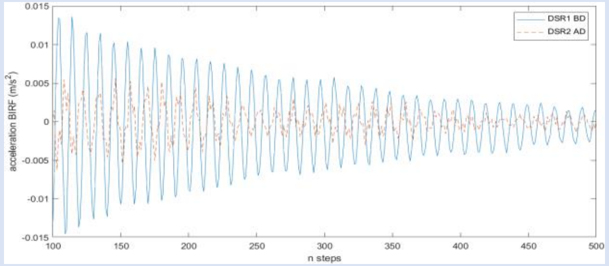

Figure 4: DSR extracted from 400 steps of the free vibration phase of the response of the undamaged and damaged structure excited by a 14 Hz harmonic force.