Structural Health Monitoring Methodology in Aircraft Structures

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ABSTRACT

There are two general approaches to Structural Health Monitoring (SHM), and particularly damage identification: vibration model based methods, such as modal and mode shape curvature analysis, and signal processing based methods such as wave propagation and signal interpretation. The former studies the changes in natural frequencies and mode shapes due to damage and may define damage index to compare healthy and damaged states, and the later includes wave propagation and signal interpretation tools like wavelet and fast Fourier transform to identify the presence of damage, its location and extent. The defined thesis will consider both areas and their application in aircraft structure. It will investigate the idea of design for SHM at early stages of design to effectively conduct diagnosis and prognosis of the potential damage. Optimizing the number of required sensors to identify the damage and minimizing the sampling rate to achieve real time data processing will be investigated. New theories like compressed sensing will be employed for sampling rate minimization.

1. EXPECTED CONTRIBUTION

The expected contributions of the thesis are:

1.1 To investigate the possibility of design optimization for SHM at early stages of design. The objective is to optimally design the structure so that it becomes more damage detectable yet safe enough under different loading conditions.

1.2 Introducing a damage index based on H_2 norm of system using its transfer function

1.3 Implementing the concept of newly developed method of compressed sensing (C.S.) in damage identification area. The approach aims at finding the most sparse and concise representation of sampling signal. The theoretical foundation of sampling process goes back to admiring work of Kotelnikov, Nyquist, Shannon, and Whittaker. Despite the revolution and advancements in computation speed based on Moore's law, in many important and emerging application such as SHM the resulting Nyquist or Shannon rate is very high that one end up with too many required samples. Hence it will be costly or even physically impossible to build devices that acquire samples in desired rate.

C.S. has emerged as a new framework in acquiring signal and sampling process and sensor placement design. This thesis will follow to implement this concept in SHM.

2. PROPOSED PLAN

This work has started from September 2010 and the expected graduation date is spring 2013. The following sections are describing the work performed since now and the future plan.

2.1 Performed work

A literature review is on progress. Initially, it is decided to examine the vibration based approach and its capability to locate the damage using a proper damage index. A 2D structure with frame element is considered (Figure 1) and a number of sensors are located on different locations.

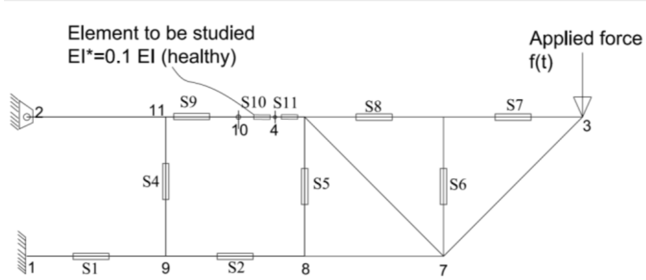

Figure 1 – A regular 2D frame structure with 11 sensors located on different elements.

The FEM model of the structure is built and the H_2 norm of the structure is defined. The H_2 norm is a good indicator which is sensitive to system input and output, system natural frequency and damping. Also it is sensitive to sensor location.
If damage is modeled by reducing the stiffness in one member at one of sensor locations (S_{10} in figure 1) the derived H_2 parameter reduction percentage from healthy to damaged structure is defined as damage index (D.I.). Figure 2 shows this parameter at different sensor locations. It is obvious that the reduction at S_{10} is the maximum as expected.

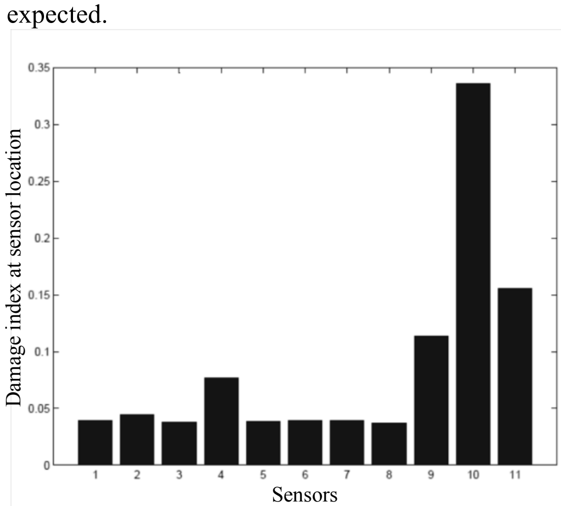

Figure 2 – D.I. in 11 different sensor locations

The interesting result is that if the damage is introduced to more than one element the D.I. response is again reliable even in the presence of some Gaussian noise. Naturally one should add more sensors to increase the sensitivity of the method.

2.2 Future plan

The work still is in its preliminary stage and the steps below are scheduled:

1. The idea of D.I. based on H_2 norm will be applied on fuselage structure of aircraft (3D model) as well, and the efficiency of the method will be tested.

2. The idea of design for SHM will be followed. This includes optimizing the embedded sensor locations and the required sampling rate in aircraft structures. Also there is an idea to use unequal lengths of structural members to have more sensitive system dynamic response to damage (This is an idea and is not tested yet).

3. Study the damage identification in plate structures as well as frame structures.

4. Landing loads will be simulated while studying the fuselage structure response based on FAR regulations.

5. The C.S. method will be used to reduce the sampling rate and computation costs to take one step toward real time computations.

6. Wavelet data analysis techniques will be applied in order to process the simulated time domain data and extract features to detect and localize damage.