Instantaneous Structural Damage Identification using Piezoelectric-based Lamb Wave Propagation

ABSTRACT

In this project, Lamb wave based structural health monitoring (SHM) techniques that do not require the multiple sets of training data will be developed. The promise of this technique is to deploy the sensors and actuators for Lamb wave SHM in such a way that several common features of the undamaged sensor-actuator paths can be instantaneously identified, thereby a path affected by structural damage could be separated in near-real time. The features that will be used in this project are the time-of-arrival, the magnitude and the shape of the propagated waves, and several more will be identified during the project period. For the undamaged structural condition, it is expected that these features possess the same characteristics if the sensors and actuators are equally spaced on the isotropic structural material. Several sensor-actuator deployment schemes will also be explored, and fundamental signal processing tools to efficiently separate the damage paths from undamaged ones will be implemented. This project will explore the feasibility of this proposed active-sensing damage detection techniques on representative structures, and outline several issues that can be used as a guideline for full-scale development of this useful structural damage diagnostic concept.

PROJECT OUTLINE

The process of implementing a damage detection strategy for aerospace, civil and mechanical engineering infrastructure is referred to as structural health monitoring (SHM). Here damage is defined as changes to the material and/or geometric properties of these systems, including changes to the boundary conditions and system connectivity, which adversely affect the system's current or future performance.

Lamb wave propagations based on the novel use of piezoelectric materials have been widely used in SHM applications. Piezoelectric materials are very useful in SHM because they can perform both duties of sensing and actuation within a local area of the structure. Piezoelectrics are a class of materials in which there is a coupling between mechanical and electrical domains. Therefore, this type of material generates mechanical strain in response to an applied electric field. Conversely, the materials produce electric charges when stressed mechanically. This coupling property allows one to design and deploy an "*active*" and "*local*" sensing system whereby the structure in question is locally excited by a known and repeatable input, and the corresponding responses are measured by the same excitation source. In Lamb wave propagations, one piezoelectric acting as an actuator generates an elastic wave through the structure, and responses are measured by an array of piezoelectric sensors. This wave generation then switches to the next piezoelectric patch and continues until the time-domain Lame wave signals from every possible sensor-actuator pair have been recorded. The changes in wave attenuation, reflection, and the time of arrival are typically used to detect and locate damage by comparing the current measurement to those measured in the pristine stage.

Although the SHM process requires the comparisons between the sensor responses of a healthy structure (baselines) and the structure after a damage occurred, measuring and maintaining the robust database of baseline signals is still challenging because of the effects of environmental condition changes, the requirement of data storage, and further, the issues associated with the

recalibration needs. In this study, therefore, we will investigate the feasibility of extracting the baseline features instantaneously so as to minimize the deterioration of the baseline signals over time.

To achieve this goal, we will systematically investigate several sensor-actuator deployment schemes, in which several common features of the undamaged sensor-actuator paths can be instantaneously identified. A path affected by structural damage will show deviation from this feature, thereby being separated from the undamaged paths. Several features, including the arrival time, the magnitude and the shape of the propagated waves will be first utilized for this study, and several more will be identified and tested during the project period. Several sensor-actuator deployment schemes will be explored, and fundamental signal processing tools to efficiently separate the damage paths will also be developed and implemented. Furthermore, it has been demonstrated that the installation status of the sensors and actuators modifies the measured Lamb waves. Therefore, a critical success to this proposed method is the ability to check the operational and installation status of the sensors and actuators. The piezoelectric sensor-diagnostic process, which was developed by the LANL researchers, will be used in the all stage of this project to ensure the success of the proposed concept.

If successful, the project will significantly impact on the current practice of the Lamb wave-based SHM techniques. The method will not only alleviate the need of the long-term stability of the database of the baseline signals, but also this method may be able to identify pre-existing structural defects that could not be identified with existing techniques. This project will explore the feasibility of this proposed active-sensing damage detection techniques on representative structures, and outline several issues that can be used as a guideline for full-scale development of this useful structural damage diagnostic concept.

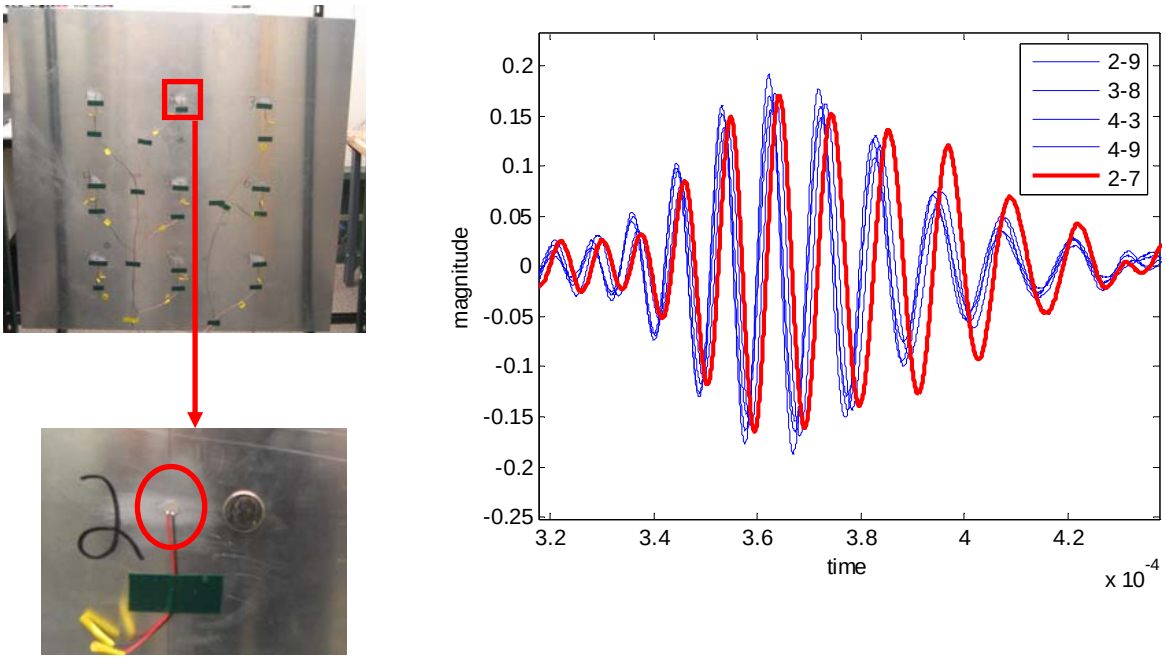

Figure 1. Preliminary testing on an Aluminum Plate, responses from undamaged (blue) and damaged paths (red)

SCHEDULE

Weeks	Tasks
1	Orientation
2	Background research on the topics of piezoelectrics and papers listed below
3	Installation of PZT and MFC patches to Al panels. Hardware use orientation.
4	Vibration testing/modal analysis of the structure with accelerometers
5	Experimental investigation using Lamb wave propagation. Data analysis
6	Experimental investigation using different sensor-actuator deployment schemes. Data analysis
7	Experimental investigation on composite plates and honeycomb AL panels
8	Begin write-up, reiterate tests, codes, etc as needed.
9	Writing up of results and presentation

HELPFUL REFERENCES

1. Sohn, H., Park, G., Wait, J.R., Limback, N.P., Farrar, C.R. 2004. "Wavelet-based Signal Processing for Detecting Delamination in Composite Plates," *Smart Materials and Structures*, **13**(1), 153-160.
2. Hay, T.R., Wei, L., Rose, J.L., 2003. "Rapid Inspection of Composite Skin-Honeycomb Core Structures with Ultrasonic Guided Waves," *Journal of Composite Materials*, **37**(10), 929-939.
3. S.S. Kessler, S.M. Spearing, C. Soutis, 2002. "Damage Detection in Composite Materials using Lamb Wave Methods," *Smart Materials and Structures*, **11**, 269-278
4. J.B. Ihn, F.K. Chang, 2004. "Detection and monitoring of hidden fatigue crack growth using a built-in piezoelectric sensor/actuator network: II. Validation using riveted joints and repair patches," *Smart Materials and Structures*, **13**, 621-630
5. Park, G., Farrar, C.R., Rutherford, C.A., Robertson, A.N., 2005, "Piezoelectric Active Sensor Self-diagnostics using Electrical Admittance Measurements," *ASME Journal of Vibrations and Acoustics*, in press.
6. Park, G., Farrar, C.R., Lanza di Scalea, F., Coccia, S., "Performance Assessment and Validation of Piezoelectric Active Sensors in Structural Health Monitoring," *Smart Materials and Structures*, submitted.