Laser Ultrasonics for Hybrid Structural Health Monitoring

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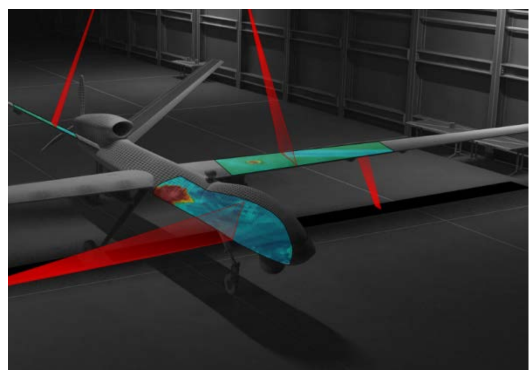
Abstract

Structural health monitoring (SHM) has failed us. After nearly 20 years of SHM R&D, nondestructive testing (NDT) is still the primary, if not only, means of identifying structural damage in practice. The problem: measurement density and quality. Why is it that one can look at an NDT ultrasound scan and just *see* the damage, but it takes a high-power machine learning algorithm to *guess* at whether an SHM measurement indicates damage? It is because there is so much data obtained from an ultrasonic scan that it is self-referencing. The damaged regions are apparent because they look significantly different from the healthy regions in the same scan. SHM researchers do not have the luxury of placing an embedded ultrasonic transducer at every pixel in a scan area, so they can't achieve the fidelity of a full NDT scan.

In this project, you will develop a new SHM paradigm that combines the online, embedded, non-disruptive monitoring capability of SHM with the measurement fidelity of NDT. In this paradigm, an array of embedded ultrasonic transducers will excite and measure ultrasonic wave pulses to provide stage-one online damage detection and rough localization. When this array ***suspects*** the presence of damage, a subset of the same transducer array will go into "buzz" mode, setting up steady-state ultrasonic waves in the structure near the damage. For stage-two, a scanning laser will be introduced to measure the full field ultrasonic response in that area in order to verify the presence of damage and provide high-fidelity localization and characterization. In other words, the embedded transducers both tell the scanning system where to look and provide the necessary distributed excitation, making the scanning system faster and less intrusive than any other scanning technology in existence.



Project Outline

Goal

Research, design, build and test a two-stage ultrasonic SHM prototype for rapid, high-fidelity detection and characterization of structural damage.

Motivation

Present structural health monitoring technology is not sufficiently reliable, accurate, or informative to drive critical decisions regarding a structure's readiness. NDT meets these criteria, but is too slow and too disruptive to be used regularly. There is a need for a system than can combine the strengths of SHM and NDT.

Procedure

1) Research ultrasonic guided wave physics, sensing hardware, and processing algorithms.
2) Design and build a prototype adaptive distributed excitation system than can both make rough estimates on damage location and optimally direct energy to those areas for scanning.

3) Test stage-two identification: Laser scanning combined with adaptive distributed excitation for imaging known surrogate and real defects.

4) Test stage-one identification: Rough defect detection and localization using distributed excitation system in isolation.

5) Combine stage-one and stage-two damage identification

Background Literature

During this project, you will learn **a lot** about signal processing, structural dynamics (especially ultrasonics), data acquisition, and programming.

To get you started, here are some Wikipedia topics you should look up: Lamb waves, guided wave testing, continuous scan laser Doppler vibrometry, analytic signal**.**

In addition, here are some articles to get you up to speed in the field:

Raghavan A, Cesnik CE. Review of guided-wave structural health monitoring. Shock and Vibration Digest. 2007;39(2):91–116.

Flynn EB, Todd MD, Wilcox PD, Drinkwater BW, Croxford AJ. Maximum-likelihood estimation of damage location in guided-wave structural health monitoring. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Science. 2011;467(2133):2575 –2596.

Flynn EB, Jarmer GJ. High-Speed, Non-Contact, Baseline-Free Imaging of Hiddden Defects Using Scanning Laser Measurements of Steady-State Ultrasonic Vibration. In: Structural Health Monitoring 2013. Stanford, CA: DEStech Publications, Inc.; 2013. p. 1186–1193.

Week by Week Plan

Week 1	Review literature and become familiar with equipment
Week 2	Design and /instrument distributed excitation system
Week 3	Write control algorithms for excitation and scanning
Week 4	Test scanned damage identification
Week 5	Write control algorithms for embedded damage identification
Week 6	Test embedded damage identification
Week 7	Test in-lab two-stage damage identification
Week 8	Demonstrate full system on a Boeing 737 at the aging aircraft facility
Week 9	Prepare report and presentation

Real World Design Issues as a Project Consideration

During the nine weeks, you will focus on a small set of structure types and damage modes. However, when making your design choices, you will need to think about all the potential application spaces. Also, the final goal of the project will be a demonstration on a real Boeing 737 aircraft, so your system will need to be flexible and robust enough to be deployed in the field.

Equipment Requirements

- High speed data acquisition system (analog input and output)
- DAQ channel matrix switch for directing excitation
- Scanning laser Doppler vibrometer

Software Requirements

- Matlab with data acquisition toolbox