Use of Artificial Neural Networks to Detect Damage in Composite Laminates

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Abstract. A novel method of damage detection in composite laminates through the use of using artificial neural networks to interpret ultrasonic sensor signals has been investigated for this research. Four sensors were placed 4.25 in apart. In a pitch-catch method, strain waves produced by one sensor, used as an actuator, passed through the material and were received by the other three sensors. The received waves are then analyzed by artificial neural networks and a damages severity and position were predicted. This system has been trained to identify damage location using as orderly collection of known simulated damage for actuator signals ranging from 50 kHz to 100 kHz. The system of four sensors was demonstrated to predict the damage location with high accuracy, compared to other methods. The research presented is a novel method of interpreting ultrasonic signal analysis with artificial neural networks to locate damage within a four sensor region.

1. Introduction

Maintenance has remained an important issue in the aerospace field. As technologies have improved composites have begun to replace metallic structural components. However, these still have a long expected life for service use and damage can occur within that time. A goal of many researchers and companies is the development of a structural health monitoring system. Such a system would be capable of identifying and locating damage in a structure in-service through a network of sensors. Ultrasonic sensors can be placed on or within composite laminates to scan for damage. Signal analysis from this method has become increasingly difficult as components have changed from metals to composites. By using small piezoelectric disks bonded to the surface or embedded within the composite structure, ultrasonic elastic waves can be introduced into the laminates and damage can be detected through changes in the wave signal. [1,2] Current methods of signal processing for ultrasonic testing can often be very processor intensive. [3,4] This is further complicated by the many shapes and sizes of the airfoil and laminate layup of wind turbine blades. This paper investigates a novel method of creating an artificial intelligence system for signal processing, which could become adaptable to the various wind turbine blade configurations. The system investigated could be capable of adapting to changes in the structure components and determine the position and size of damage

2. Experiment, Results, Discussion, and Significance

An experiment was conducted for damage location on a composite laminate. The composite laminate was of carbon fiber and epoxy materials and had a layup of $[0/\pm45/90]_S$. The setup allowed for a quasi-isotropic state. This type of composite laminate is found in many aerospace engineering applications. Four piezoelectric ceramic disks were bonded onto the surface of the composite with the orientations shown in the figure below. These sensors acted as sensitive microphones and speakers for sensors and actuators respectively. A pitch-catch system was utilized. Each piezoelectric ceramic was used as an actuator to release an elastic wave into the material. The three remaining disks were used as sensors to receive a signal. This system formed twelve actuator-sensor paths. The actuator released elastic waves for 50 kHz, 75 kHz, and 100 kHz. These frequencies were high to detect small damage, but low enough to include only one wave mode to be received, simplifying the received signal.
Damage was simulated on the surface of the laminate by means of a wafer. The wafer sizing ranged from 0.375 in to 1.5 in. The simulated damage was similar to that of delamination areas of smaller area. The damage was placed at twenty-five different locations within the area formed by the piezoelectric disks and scans of damage locations were performed. An additional five locations were used outside of the area to examine the capability of scanning outside the region. The damage size and location placement was performed in a randomized order and each location was repeated three times. Ultrasonic testing operates by comparing the wave signal of an undamaged state, commonly called a baseline signal, to a current signal with possible damage present. The baseline signal

was consistent throughout the experiment, minimizing some unknown variables of the experiment. The analysis of wave travel in a composite is difficult to model, unless a complicated finite element model is utilized. [1,3] The wave mode signal received by each of the sensors was compressed to wave properties of amplitude and time-of-flight. These were compared to the baseline signal, forming inputs for analysis, the change in amplitude and the shift in the time-of-flight of the wave.

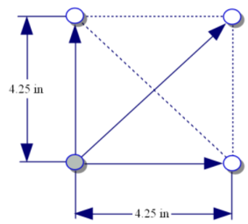
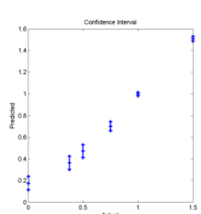
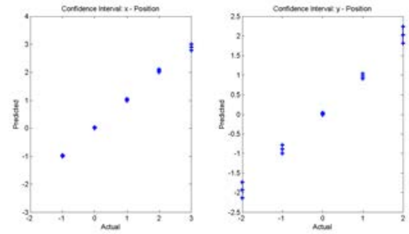


Fig. 1. Piezoelectric disk placement. Each sensor would pulse a signal to the remaining three through the material.

The changes in the path signals from all twelve paths were inputted into a series of feed-forward artificial neural network. The first network had an architecture of consisting of three hidden layers with hyperbolic tangent activation functions. The output of the network was a damage sizing. The results are presented in 95% confidence intervals to account for a spread in variation in artificial neural networks. The goal of this network was to determine if damage is present or not. With 95% confidence level, damage of 0.5 in and larger is able to be detected. The data was filtered so that if the network predicted no damage, then it was dropped from the dataset. The remaining data was then fed into another feed-forward neural network. The inputs for this included the original twelve path signals along with the output from the damage sizing position. This network then output the damage position in Cartesian coordinates. From the results in Figure 2b, there was significant differences in determining the location of the damage location in a two dimensional plane with 95% confidence. Through this experimentation the four sensor network has been verified to be capable of scanning for damage. A network first determines the size, ranging from no damage present to damage the size of 0.5 in and greater. If damage is present, then a second network determines the location of damage.



(a) Damage sizing



(b) Damage Positioning

Fig. 2. Results from feed-forward network comparing the actual damage sizing (a) and position (b) to the networks' predicted values.

This experiment was an initial stage in determining the effectiveness of a structural health monitoring system. The next phase would be to assemble multiple squares, forming a sensor network. The results could be combined by committee networks or multi-agent systems. The results gained from this research allow for a modular network of sensors, which could be installed on aerospace structures. These could scan for damage and locate problem areas of interest. Further research would entail a reliability analysis of the damage region to determine the remaining life.

3. Conclusions

Four ultrasonic sensors were placed on a composite laminate and damage was simulated. Through artificial neural networks the system could identify damage presence and severity as well as locate it. This research shows promise for a structural health monitoring system.

4. Acknowledgements

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