Neural Network/Knowledge Based Systems for Smart Structures

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Abstract

In this paper, we present an approach for the design of intelligent structural monitoring systems. This approach consists of integrating of artificial neural networks (ANNs) and knowledge based expert systems (KBs) in order to achieve maximum benefits from both. We demonstrate our approach using a specific application involving the detection and isolation of in-flight aircraft structural damage, with assessments to determine the structure's residual strength. Our smart structures system uses strain measurements as sensory inputs. These strain distributions are obtained by embedding sensors, such as fiber optics, within composite aircraft structures. In general, ANNs process these multiple sensor measurements in parallel, while the KBs evaluate the results.

The primary development objective is to use the complementary capabilities of neural networks and expert systems within appropriate tasks and to determine integration strategies for creating structural monitoring systems. The smart structures system development takes place within the in-house developed *NueX* Hybrid Environment. In particular, ANN input and output nodes are represented as objects within the knowledge base, thereby supporting the inheritance of structural information. The ANN architectures, including node connection paths and corresponding weights, are stored in an efficient external data structure. The executive controller for the smart structures system is handled by a specialized KB; *NueX* allows the executive KB to pass information to and from the ANNs. Structural information regarding geometry and sensor locations is stored within a structural KB, which also performs structural reasoning on the relationships between sensor locations and critical aircraft components. Failure Detection and Isolation (FDI) is accomplished by both ANNs and KBs. The results from the FDI are evaluated within the Damage Assessor (DA), which also includes ANNs and KBs. The DA is responsible for determining the structural residual strength and the effects of damage on critical components such as hydraulic lines.

In our hybrid smart structures methodology, ANN development is accomplished using a structural class based approach. Typically for large aircraft structures, finite element models are only available for specific critical locations, and it is desirable to minimize the need for further analyses. Therefore, a variety of general structure classes are defined such that the majority of the structure is represented; finite element models need only be available for a representative of each of these general locations. The structures investigated consist of skin sections, skin/spar interface sections, corners, and skin boundaries. For each of these general classes, specialized ANNs are developed to process the sensor measurements which relate to that particular structural class. ANN training data are obtained by subjecting each section's finite element model to the largest range of loading conditions that its particular class may encounter over the structure and over the load spectrum of the aircraft. In doing so, the resulting ANN can be used over any location on the structure that matches its class. One of the ANN tasks involves estimating each sensor's undamaged strain measurement based upon its neighboring strain distribution. If this estimate

significantly deviates from the sensor's actual strain reading, structural damage may be present and the expert system is alerted. Additional neural network tasks include serving as a damage dictionary and recognizing damage from temporal strain signatures.

The performance of our smart structures system is evaluated using finite element models and experimental results. The neural networks are trained with finite element data from an advanced high-strain composite wing section (manufactured by Grumman Aerospace Corporation), referred to as the Survivability Element. This structural section consists of one skin panel with three attached spars, therefore incorporating all four structural classes previously defined. The system is initially tested using the Survivability Element model with two damage scenarios. Subsequently, a hardware breadboard demonstration is performed on a composite skin panel incorporating one damage scenario. Finally, high-strain wing subcomponent test results are used to evaluate the system's performance on a large wing center section of which the ANNs have not been specifically trained, yet incorporates the same structural classes.

A smart structures design tool, based upon these hybrid concepts, will assist in the specification of optimal sensor locations, selection and training of ANNs, and the development of a structure-dependent knowledge base. These steps will be performed iteratively by the structural designer using our smart structures design tool, along with CAD and finite element programs. In this manner, engineers will create intelligent structural monitoring systems designed specifically for their applications.