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SMART SENSOR SYSTEM FOR NDE OF CORROSION IN AGING AIRCRAFT

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INTRODUCTION

The extension of the operation life of military and civilian aircraft rather than replacing them with new ones is increasing the probability of aircraft component failure as a result of aging. Aircraft that already have endured a long service life of more than 40 years are now being considered for another 40 years of service. Such a life extension has added a great degree of urgency to the ongoing need for reliable and efficient NDE methods. In contrast to crack detection, for which many NDE methods are available, corrosion damage is difficult to detect particularly at the initiation stages. Corrosion damage is costly to the aircraft operators and, in case of catastrophic failure, carrying the risk of loss of life and hardware. A futuristic idea is presented herein to take advantage of the accumulating knowledge and understanding of material degradation caused by flaws. A knowledge-base system combined with a series of sensors that monitor the variations in the material state supported by effective computing power can be used to simulate the process of degradation and to establish a health monitoring system. While this paper concentrates on corrosion, the concept is generic and can be adapted to other type of flaws. Corrosion [1] is a complex electro-chemo-mechanical process of material degradation, which depends on a large number of variables, with some that are difficult to identify *a priori*. The idea is to model the corrosion growth as a mathematical transformation operator that transforms the material characteristic variables to a degraded state. Such a model can be used to simulate the corrosion process and incorporate the parameters that characterize the material state and the level of corrosion damage. The input to the corrosion simulation system emulates data that is obtained in real time from selected sensors. Data fusion of sensor signals and artificial neural network algorithms [2] can enhance the accuracy of the damage characterization and reduce the effect of uncertainties and nonlinearities. The monitoring system can be complemented by an expert system with knowledge base, which would contain the information and heuristic rules used by inspectors to make decisions regarding the integrity of a corroded structure. The developed hybrid system will improve the understanding of corrosion processes, the monitoring of the associated material degradation, and the integrity assessment of the instrumented structure.

CORROSION DAMAGE CHARACTERISTICS

Corrosion detection with current NDE methods is time consuming, demands great attention to details by inspectors and, in many cases, and requires a costly disassembly of the structure. The reliability of the test results hinges heavily on the type of instrument used, the condition of the instrumentation, the method and environment under which it is operated and, above all, the inspectors' interpretations. This interpretation depends critically on the inspectors' experience, competence, attentiveness and meticulous dedication. The use of field robotics to help inspectors by automating the data acquisition, archival and processing has failed so far to be adopted by aircraft developers and users because of the cost and complexity of current robots. Addressing the need for effective NDE methods requires understanding the complex electro-chemo-mechanical process of corrosion. Corrosion is a relatively slow material degradation that is involved with the exposure of the aircraft metallic structure to service conditions. Corrosion can appear in many forms, depending on the type of metal, how it is processed, surrounding structure and service conditions. Corrosion results from exposure to humid or corrosive environment and involves primarily electrochemical action at chemical/metallurgical/physical heterogeneities, which are exhibiting dissimilar potentials. The corrosion process in the presence of liquids can best be described as a local galvanic cell between the base metal (anodic sites), at defects in the protective coating, and passive (cathodic) sites. Corrosion protection is an established technology for preventing or inhibiting the corrosion damage on aircraft structures. However, over long periods of aircraft service there is a high probability of failure of the protection methods. Severity of corrosion attack varies with aircraft type, design technique, operation environment and operator's maintenance program. Surface corrosion in its embryonic stage can be detected visually seeking indications such as discoloration, faint powder lines, pimples on the paint and paint damage. On the other hand, concealed corrosion is very difficult to detect since in many cases the characteristic of the damage is not sufficient to trigger an indication in a conventional NDE method. In many cases, the damage reaches a very progressive stage before it becomes detectable and an expensive disassembly of the structure may be required. In order to effectively monitor corrosion throughout the life of the structure and provide data about the severity of the damage it is essential to employ a smart sensing system.

SMART MONITORING OF CORROSION

The technology advancement in real-time computing, sensors, data fusion and artificial intelligence (e.g. neural networks and expert systems), as well as the understanding of the mechanisms of corrosion damage and their effects on the host structure, can be used to simulate the degradation process and to develop a real time monitoring capability. A smart multiple-sensor system of monitoring corrosion on aging aircraft can be devised, such as the one depicted in Figure 1. Corrosion can be modeled analytically and simulated to investigate the structural degradation to select an effective combination of sensors. Modern genetic programming algorithms can be used to find an optimal number and/or location for the sensors, such that information obtained is maximized. The corrosion process, the effect on the material properties/damage and sensors' response can be treated as a transformation operation.

A mathematical operator can be applied to the tensor that characterizes the material state in order to determine the resultant tensor describing the degraded material. Selected properties that are affected by corrosion can be used to form the characteristic tensor. Since the analytical problem is expected to involve a series of nonlinear equations with no closed form solution, neural network models will be used to assist in characterizing the transformation operator and the resultant tensor. A neural network algorithm can be used to learn the influence of corrosion on the material parameters (the transformation operator) and consequently characterize the damage (resultant tensor). This approach can be used to minimize characterization errors and the uncertainty associated with the large number of variable related to corrosion. The

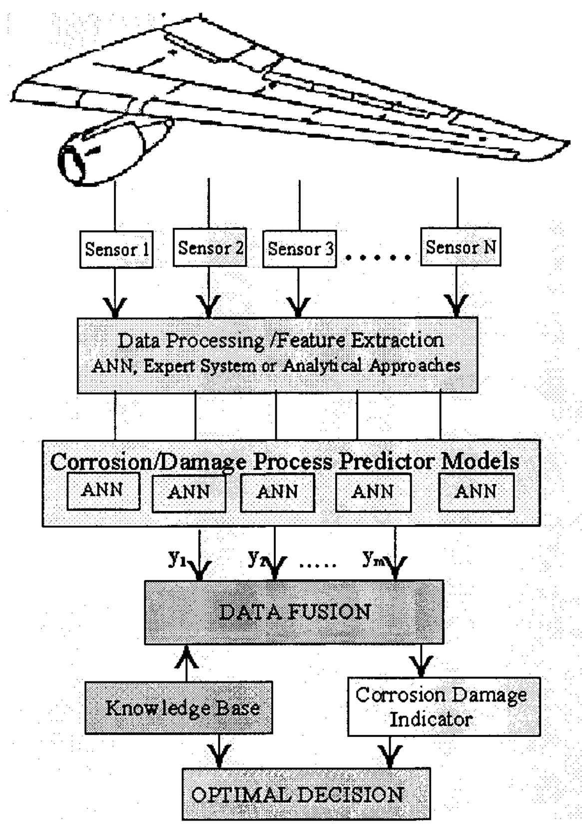

Figure 1: Smart System for NDE of Corrosion

corrosion data can be processed using knowledge-based, learning and decision-making rules. One possible advantage for using neural network tools is that they could assist in predicting the complementary corrosion data from partial data sets that can be obtained from a practical system of multiple sensors. Such an approach can be used to improve the understanding of the process of corrosion damage. Also, it can be used to develop (a) models that relate sensors' response to corrosion damage; (b) simulation algorithm for corrosion process and sensor measurements; and (c) neural network based scheme for corrosion detection and characterization. The approach can later be extended to the broader problem of defect characterization. Efforts to adapt a similar approach were reported for the investigation of the growth of fatigue cracks [3]. Initially, the input will be obtained from a simulated corrosion process and later from an accelerated corrosion degradation experiment. Neural networks will need to be trained to learn the task and to reason using information from distributed sensors. Non-linearity in the data can be processed by adaptive control algorithms where the linear gains are substituted by nonlinear neural network [4]. Strategies of transferring sensor responsibility from one group to another will be employed to allow use of different capabilities of the various sensors and to effectively respond to conditions of sensor malfunctioning. The relationships between the signals from the sensors, the presence of corrosion and the performance/integrity of the structure are not known *a priori* and are likely to be related in a very complex way.

SENSORS FOR IN-SITU APPLICATIONS

In contrast to conventional NDE, the use of sensors can provide information at any desirable moment and it eliminates manual tests assuring consistent and reliable test results. The same sensors can also be used for other monitoring tasks of quality/integrity monitoring from production through service life. A system that uses multiple micro-sensors located strategically on an aircraft structure can provide better understanding and control of the process of corrosion [5]. The corrosion electrochemical reaction is induced by the presence of impurities, either metallurgical (e.g., grain boundaries), mechanical (e.g., kinks and stressed areas), chemicals (e.g., dissimilar metals) or physical joints/interfaces. Sensors for corrosion monitoring gauge various parameters of the process, the physical damage, property changes or presence of by-products. There are considerable challenges to overcome before in-situ sensors are deemed reliable and affordable for a monitoring system. Some of the challenges are related to the interaction of corrosion with sensors, physical integrity, robustness, integration, cost, etc. Generally, the use of in-situ sensors to monitor corrosion can significantly reduce the need for conventional inspection that require disassembly and provide support for a concept of disassembly for cause. In such case, parts can be removed or refurbished only on the basis of relevant input from the sensor system.

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