CONDITION BASED MAINTENANCE USING ARTIFICIAL INTELLIGENCE FOR STRUCTURAL HEALTH MONITORING IN AVIATION INDUSTRY

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Abstract- This paper does a study on using structural health monitoring for condition based maintenance in aviation industry. Also, use of latest innovative advancements in Artificial Intelligence has been explained in this paper for dovetailing in the aviation sector. The Indian Air Force being the fourth largest Air force in the world has a large number of assets that is non indigenous. These highly expensive military aircraft, missiles, early warning systems, aerostats etc are susceptible to failure over a long run of operation or storage. Unfortunately we generally come to know about damage only after it has reached a significant level after which we are forced to further purchase spares or go for expensive refits. Either way, the optimum option of having early damage detection and to get the rectifications done under warranty period itself is not being implemented. In this scenario, the necessity of implementing structural health monitoring systems for the purpose of damage detection is quintessential. The results to a large extent need human interpretation for effective cost saving and to ensure condition based maintenance rather than schedule based maintenance. With the present pattern recognition systems that have been developed, it will be feasible to have an artificial intelligence program to scan through the large amount of data generated and give predicted results on impending failures.

Keywords- Structural Health Monitoring, Condition Based Maintenance, Defect Investigation, Artificial Intelligence

I. INTRODUCTION

In Indian Armed Forces, aviation sector is predominantly handled by IAF with a small segment being held by Indian Army and Indian Navy. Due to the emergent need for having technological advantage, India had to resort to imported platforms in aviation sector. This led to a varied legacy technology leading to maintenance schedule which is totally characteristic of particular aircraft or system. The schedule based maintenance results in tremendous demand on man hours and spares. As most of the spares are also imported, this leads to further burden on the exchequer.

Structural health monitoring, is an emerging field and across the globe scientists are working on developing techniques for various fields which includes aviation, civil, infrastructural, electronic and seismology. There is a need to optimize the technologies prevalent to suit our need of implementing condition based maintenance which shall entail better utilization of vital resources. The Wind and Structural Health Monitoring System (WASHMS) and Huey P Long Bridge systems were evaluated and it has been illustrated how the existing technology and results of available research can be used in aviation sector. Lot of work has been done in the field of civionics involving plugging of the microstrand Nano Differential variable reluctance transducer (DVRT) sensors into the structure to get active integrity information. Another model of interest is the software tool suite created in Illinois structural health monitoring project (ISHMP) for Jindo bridge has a very practical approach. The use of such SHM techniques in the field of aviation incites particular focus on the nuances of an airborne platform. Further when this platform is used as a weapon platform, a gamut of technological challenges arises. In the presence of heavy electromagnetic interference, natural or as Electronic Counter Measures, is addressed by the solution of embedding these sensors inside the fiber epoxy layers of the composite structure. The thin plate structure and the lightness of structure are special characteristics of aircraft and missile structures. A lot of research has been conducted and experiments were tabulated for the effectiveness of damage detection and importantly identification. The onus is on cost effectiveness. The illustration can have unique approaches, wherein in our paper we show how the stress analysis of civil infrastructure can be customized for aviation structures. The experimental studies were carried out and the initial results are proving that we can rely on the test results for implementation of SHM in missile and aircraft load bearing parts. This experimental setup and interpretation of results are produced in this paper. The results to a large extent need human interpretation for effective cost saving and to ensure correctness of maintenance practice. With the present pattern recognition systems that have been developed, it will be feasible to have an artificial intelligence program to scan through the large amount of data generated and give predictions on impending failures. The technique uses variation in propagation of waves through different paths in the presence of a defect. Pareto optimal values can be set and the program will evaluate the data intelligently to give the optimum predications of defect. The panel under evaluation may be undergoing different types of loading especially...
random loading. Also, the variation in frequency of loading will cause the panel to undergo fatigue non-linearly.

The evaluation of the panel for structural integrity will involve ensuring that all the errors of the sensors are modeled correctly. An important technique in this regard can be those being developed for robots to be mobile and autonomous. In SHM for our aging fleets, the artificial intelligence can incorporate this same object recognition algorithm for identifying panel discoloration, bending, abnormalities and other undesirable variation in geometry. An example for implementing pattern interpretation and for object recognition using artificial intelligence has been explained in this paper. Thus, the inter-disciplinary field of SHM can be helpful when we use the existing technologies in non aviation sector to dovetail into existing air assets.

II. EXPERIMENTAL STUDY

2.1 Fracture Mechanics
We need to understand the difference between implementing SHM system in civil and other non aviation sectors to that of implementation in aviation sector. The larger projects like that in case of Hong Kong civil infrastructure SHM gives us an insight to usage patterns of various existing technologies. The challenge is to successfully incorporate this for application in the aviation sector.

The answer to overpowering of atomic bonds in development of fracture caused by stress forces is analyzed through J integral criterion and several other models. But, to estimate crack development in case of preexisting defect caused by fatigue in a brittle material of interest, we have taken the simple model using Griffiths’ theory for unstable growth of crack. The failure stress $\sigma$ relation is,

$$\sigma = \frac{2E\gamma}{\pi a}$$

Where $\gamma$ is the surface energy per unit area of the crack, ‘E’ is Young’s modulus of material, and ‘a’ is the crack length. The quantity $\sqrt[\pi]{a}$ will be different for various structures and will characterize the toughness of structure to withstand fracture. The different aerodynamic loads acting on a thin plate structure can to an extent be analyzed using the fact that many SHM systems already in use on infrastructure incorporate high wind and dynamic loading situation.

2.2 Experimental setup
The piezoelectric crystals based on PZT meeting US DOD MIL STD 1376, are mounted on the structure as shown in the figure. The plate dimensions are so chosen that the wave propagation distance is 270 mm as shown in Fig 1. Multifunction wave generator is used to give modulated tone burst to excite the piezoelectric crystal. The wave response is studied on a 2 channel oscilloscope. This specimen thereby depicts the structural complexity in an aircraft. The material for the structure is carbon epoxy and the central frequency of measurement is 95 (+/- 3) KHz.

The noise in the output signal is reduced using filters. The plate having a defect is analyzed as the propagation anomaly occurs. The discrete signal data is truncated and transformed into frequency domain using FFT. The crystals are so set that they are non-uniformly placed over the material. The objective is to accurately know the position of the defect. Such experiments have been extensively carried out for bridges and buildings. The composite and aluminium structure in our case provides a variation to that of reinforced concrete. Similarly, the bulk volume of structures such as in bridges gives a stark contrast to that of thin plate layer. But, the inherent advantage of thin plate layers is that the flaw position can be identified in 2 dimensions rather than 3 dimensions. Also the nature of flaw need not be as complicated as in civil structures. Finally the non homogeneity of structure is high and complex in bridges and civil structures as compared to the structures found in aviation sector.
The piezoelectric crystal is depicted as Star in the Fig 2. The different type of damages as are generally encountered in aviation sector is incorporated into the structure. The positions were selected to be random. Also the paths are of varying lengths. The propagated wave is characterized and analyzed. The FFT of the signal is used to compare two frequency spectra and the damage index is calculated. This gives an indication of the position of damage with respect to the source of excitation. The result of the damage location analysis as a distance from point A for each path is as given in table 1. Further the fracture mechanics as explained earlier will help us in predicting the nature of crack propagation.

<table>
<thead>
<tr>
<th>Path</th>
<th>Damage dimensions</th>
<th>Damage location from A (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No damage</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>5mm diameter hole</td>
<td>11.7</td>
</tr>
<tr>
<td>3</td>
<td>3 Cm rectangular hole</td>
<td>3.25</td>
</tr>
<tr>
<td>4</td>
<td>0.005 m deep cut</td>
<td>25.4</td>
</tr>
<tr>
<td>5</td>
<td>5mm by 0.004m wide</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 1: Location and details of defects

2.3 Artificial Intelligence
One of the main challenges for successful adaptation of civionics technologies of Structural Health monitoring into the aviation sector will be the ability to automatically detect position and type of impending structural flaws without human intervention. For this, artificial intelligence would be of interest. The current research on the simultaneous localization and map building show that the robots will be able to map new locations and also to recognize an earlier visited place. Infusion of this algorithm in our case will entail that the damage identification gets intelligently analyzed and past mapping of area is also stored in databank. The simultaneous scan of area will be done through the run of one set of activation of the process explained through the experiment elucidated wherein the desired wave propagation will be achieved and the damage location will be identified.

III. RESULTS AND ANALYSIS
Based on the experiments conducted, it is noticed that the there is difficulty in identification of modes in small dimension plates due to reflection cluttering. The Fig 3 depicts the characteristic difference in wave patterns. This means that the techniques prevalent in civionics and other sectors to identify and predict damage occurrence can be smoothly incorporated in aluminium or metal alloy based thin plate wide body structures of aviation sector. However, the composite structures will demand the mode tuning. Several experiments have already been conducted on mode tuning and simulation works are available which can be readily incorporated.

CONCLUSIONS
Analysis and review carried out on various technologies have resulted in conduct of experimental verification on feasibility of application in aviation sector. The results are promising; however the broad conclusions drawn in this paper are as follows:
1. Use of artificial intelligence algorithm for SLAM can be made to improve DI in implementation of SHM in aviation sector.
2. The techniques and sensor technology used for structural monitoring of the health of infrastructure can be dovetailed for aviation industry requirement

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