

197 The Development of a Practical Wireless Sensor Based Aircraft Structural Health Monitoring System

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Introduction

The aerospace industry is aiming for a cleaner means of transport. One way to achieve this is by making transportation lighter thus directly improving fuel efficiency and reducing environmental impact. A further aim, of the industry, is to reduce maintenance time in order to reduce operating costs, which can result in a reduction of air transport cost, benefitting both passenger and freight services. Current developments to support these aims include using advanced materials, with the current generation of aerospace structures being 50% composite materials. These materials offer a weight reduction whilst maintaining adequate stiffness; however, their damage mechanics are very complex and less deterministic than that of metals. This results in an overall reduced benefit. Structures are manufactured thicker using additional material in order to accommodate unknown or unpredictable failure modes, which cannot be easily detected during maintenance. A way to overcome these issues is the adoption of a Structural Health Monitoring (SHM) inspection system utilising energy harvesting and a wireless sensor network (Fig. 1). Such systems obtain information about the status of a structure in real time which can feed back into an asset management framework, to determine maintenance schedules and allow for lighter structures to be designed whilst increasing safety. The target components for such a system would include critical elements such as airframe, engines and landing gears.

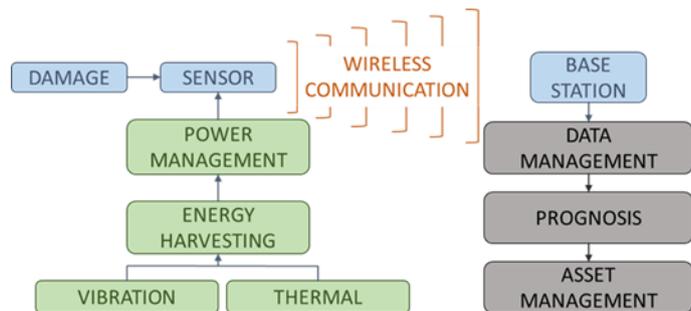


Figure 1: Example SHM System

Acoustic Emission (AE) (10-1000 kHz) based SHM systems that utilise energy harvesting for power generation and wireless sensor networks for communication are being increasingly demonstrated to be effective in monitoring damage in simple plates and aerospace components in a laboratory setting. AE is a passive system that detects and locates stress waves as a structure undergoes damage. Batteries are currently not allowed within aerospace structures and the addition of cables to power a system or transfer data adds increased weight to the aircraft, removing any benefit. An A380 has 530km of wiring, a significant additional weight. This increases fuel consumption, a significant expense to the operator [1]. Another example being a black hawk helicopter which has almost 900kg of wires [2]. Hence, energy harvesting and wireless communication are essential for any aerospace SHM system.

Sensors to Inform and Enable Wireless Networks (SENTIENT) was an Innovate UK project (#101657) with a consortium of eight partners involved, Cardiff University, the University of Exeter, HW Communications, Airbus, BAE Systems, TWI, NEDEAS and Ultra Electronics, each working on a specific element of the system shown in Fig 1. The aim of SENTIENT was to develop a low power wireless system capable of detecting fatigue damage growth in aircraft structures through the monitoring of AE. Cardiff University was responsible for designing the AE unit, with BAE systems manufacturing the system. In a low power AE system for aerospace applications, accurate time correlation between sensors cannot be achieved, due to limitations in wireless clocks. A new approach was therefore taken in which three sensors in a small triangular array which allows them to be connected to the same sensor node without excessive wiring was developed (Fig. 2). This triangle approach is able to approximate the angle of arrival of the incoming wave using trigonometry and the distance the wave has travelled can be found by using analogue frequency filtering to remove the high frequency component (S_0 mode) leaving only the lower frequency, and slower, A_0 mode. The difference in the arrival of these two modes is used with the known velocities to predict the distance. The developed hardware and sensor array are shown in Fig. 2. A number of iterations of hardware were developed to do this and the final system included data acquisition, analysis and wireless communications. The power during operation was around 17mW whilst waiting for damage and 40mW when transmitting data. A sleep mode of 0.33mW was also achieved.

Experimental Procedure

To test the system artificial fracture sources using the industry standard Hsu-Nielson (H-N) pencil lead breaks, which replicate an AE wave originating from a fatigue crack, were utilised. Tests were performed on a range of aluminium and composite structures of increasing complexity including A320 and A350 wings. Regular 100mm grids were drawn on the structures and five H-N sources at each point were used to assess the accuracy of the location approach. In all tests AE signals waves were recorded using three Nano-30 sensors (150-750kHz) bonded 75mm apart and connected to the wireless sensor node (Fig. 2) which processed the received data and sent the predicted location wirelessly to a laptop. The predicted error was then compared to the actual location and the error between the two locations identified.

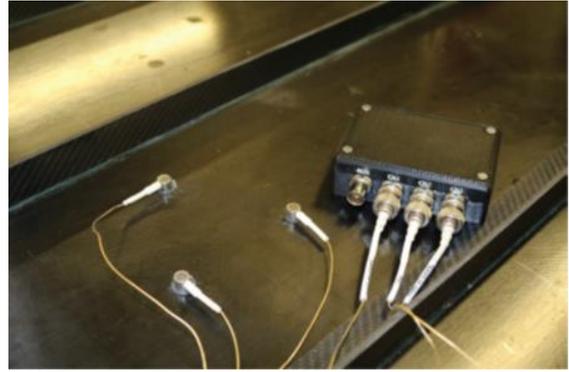


Figure 2: Developed SHM System

Results and Discussion

Fig. 3 and 4 shows the results of two investigations on an aluminium panel 1200x1200x3mm panel and a composite 900x900x3mm 16 ply quasi-isotropic composite panel. Both panels had four stiffeners bonded to the structure as shown by the red horizontal lines in the plots. The triangle of red circles represents the sensor positions. The colour maps present the average error between the calculated location and the actual location. The results presented are representative of the accuracy seen in the testing on the aircraft structures.

The testing highlights the presence of some significant errors due to the complexity of the panel, however improvements can be made with further enhancements and refinement in the developed hardware, a number of which have been identified. The results presented, however, are precise, with a high level of repeatability which would allow maintenance engineers to target inspection areas effectively and efficiently.

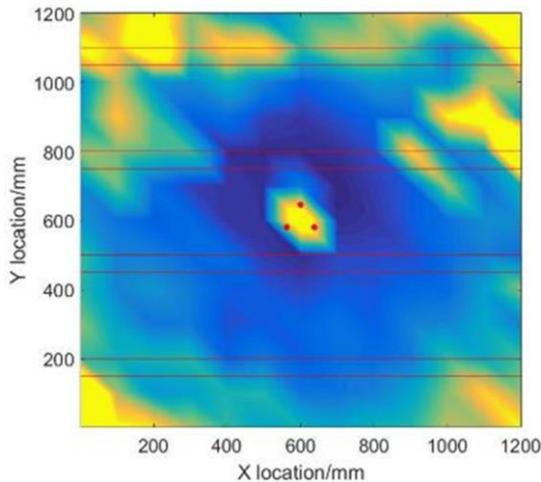


Figure 3: Aluminium panel results

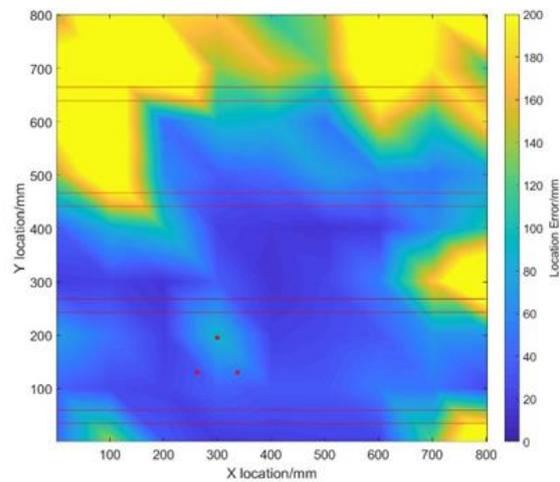


Figure 3: Composite panel results

Conclusion

The results presented have demonstrated that a low power wireless system capable of determining the location of damage is now feasible. However, significant work is now required to ensure the aerospace industry adopts such a system. Furthermore, there is an urgent need to start to integrate these SHM techniques at the inception of an aircraft, and not as a retro fit, to maximise their benefit.

References

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- [2] Jianhua, I., Demirkiran, I., Yang, t. & Helfrick, (2008), Communication schemes for aerospace wireless sensors. 2008 IEEE/AIAA 27th Digital Avionics Systems Conference, 26-30 Oct. 2008. 5.D.4-1-5.D.4-9. D.M. Maric, P.F. Meier and S.K. Estreicher: *Mater. Sci. Forum* Vol. 83 (2002), p. 119-128