Structural Health Monitoring: A Review

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Abstract

The use of Structural Health Monitoring (SHM) is a key to achieve technological leaps in the design and operation of engineering structures. Composite materials incorporating SHM systems enable the design and manufacture of tailored smart structures. This paper focuses on the application of SHM for various components including those in the maritime, oil and gas, civil infrastructure and other industries as a means of highlighting the issues that is faced by conventional methods. Incorporation of SHM has the potential to reduce through-life costs by the adoption of Condition Based Maintenance and to reduce operating costs by the design of more structurally efficient aircraft. The paper addresses the convenience involved in the design, certification, manufacture and through life support of such structures. Critical areas of development have been identified to enable the implementation of SHM in future composite structures.

***Keywords**: SHM, Sensors, Monitoring, Structures*

INTRODUCTION

Structural health monitoring is important aspect of design and modifications in engineering structures. It involves permanently attached transducers, often combined with instrumentation, and so enables frequent measurements during operation. The signals obtained are often interpreted by comparing them with previous measurements using a process commonly called baseline subtraction; the detection of damage from the sequence of signals may be automated. Different types of SHM are grouped in table 1 [1].

***Table 1:** Classification of SHM techniques [1]*

Type of SHM	Availability of standards	Type of Measurement	Applications on real systems
Machine condition monitoring	Many	Mainly passive	Multiple
			Routinely applied in industry
Global monitoring of large structures – in practice, Structural Identification (usually of large structures, for example, bridges)	Some	Mainly passive	Increasingly common in some applications but not mature
			Many trials
Large area monitoring for damage. Full coverage of a multiple such systems. structure would typically require large localised	Limited	Mainly active	A few commercial applications
			Many trials
Localised damage detection, for example, cracks and corrosion	Limited	Mainly active	A few specialist commercial applications
			Many trials

LITERATURE REVIEW

Chad Forrest et al. [2] demonstrated the Landing Gear Structural Health Monitoring System that provides diagnostics of health and usage monitoring system by direct load measurement in addition to strut servicing detection algorithm. Author addressed the following topics in the area of HUMS and CBM: (1) advanced landing gear sensors for direct load measurement; (2) data fusion of direct loads monitoring data into fatigue life assessments; (3) paradigm shifts in aircraft maintenance utilizing strut servicing detection algorithms; (4) system verification and validation; and (5) safety and maintenance benefits. This paper shows that above functions can be achieved by incorporation of new sensors in landing gear assembly. Advance landing sensors are the pressure sensor shown in figure 1. The pressure sensor is used to collect stut pressure data during a load survey flight test.

Figure 1: *Sensor assembly installation on landing gear* [2]

The benefits include hard landing detection, strut operational readiness monitoring and improved weight and balance systems.

Xiaoliang Zhao et al. [3] studied Wireless Ultrasonic Structural Health Monitoring (SHM) System for aircraft wing inspection. Two wireless ultrasonic SHM approaches were realized in this study. The first approach, i.e. the direct RF analog signal coupling approach, requires only passive transducers and an antenna to be embedded inside the structure while the energy is coupled to the transducer with an external transmitting antenna.

The second approach embeds both the transducer network and the data acquisition device into a structure, while the data can be downloaded wirelessly through a radio with good signal quality, range, and immunity to interference. Power to the electronics was delivered wirelessly at X-band with an antenna–rectifier (rectenna) array conformed to the aircraft body, eliminating the need for batteries and their replacement. Wireless system was tested with the PZT sensor array on the wing panel and was compared well with the wire connection case.

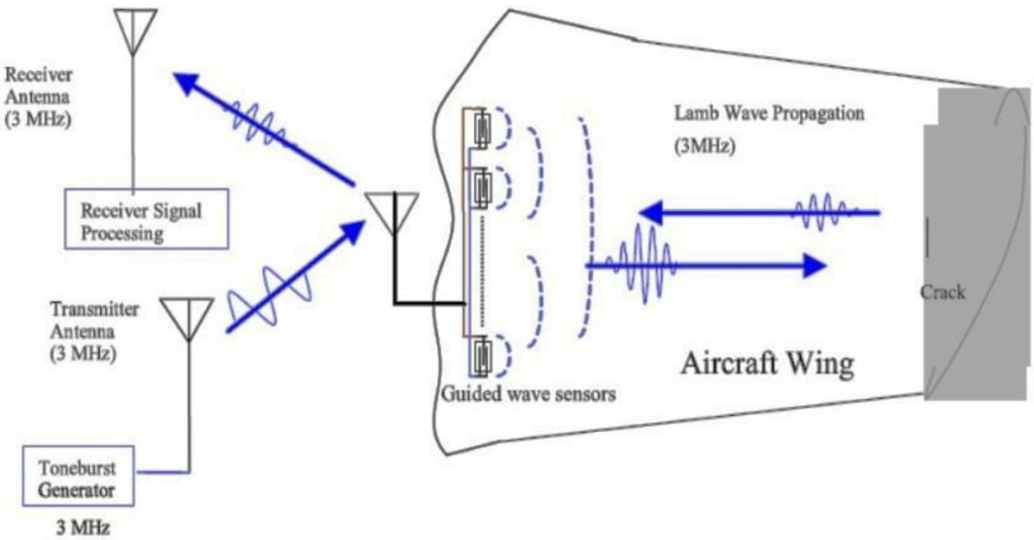

Figure 2: *Schematic view of the direct analog RF coupling approach for aircraft wing inspection [3]*

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Ting Dong et al. [4] reviewed Cost-Effectiveness of Structural Health Monitoring in Fuselage Maintenance of the Civil Aviation Industry. At first various sensors were reviewed for their detection range, detectable damage size, and installed weight, which revealed that the piezoelectric wafer active sensor (PWAS) is the most promising sensor for aircraft SHM. Secondly case study of inspecting the fuselage of Boeing-737NG using PWAS was performed. Utilizations of sensors can reduce the maintenance downtime and thus the maintenance cost is highlighted. But due to the limited detection range of the PWAS, about 10,000 sensors were required to assess the entire fuselage areas of a Boeing 737NG and thus causing increase in weight and significant loss of payload. Therefore, it was concluded that the aviation industry cannot take advantage of this new technology. In order to make the SHM-based inspection cost-effective, it would be necessary to improve the sensor technology to reduce the weight of the sensor system and to detect damage in a long range.

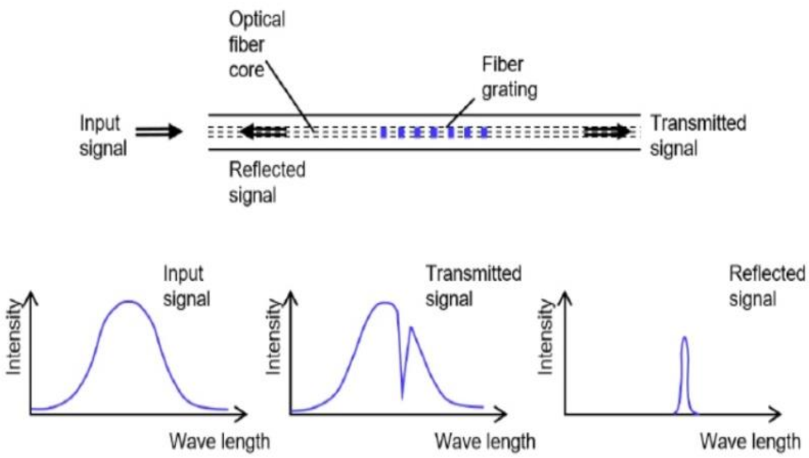


Figure 3: *Fibre Bragg Grating (FBG) sensor to detect the change in wavelength due to strain [4]*

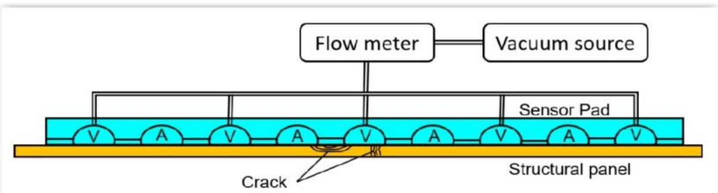
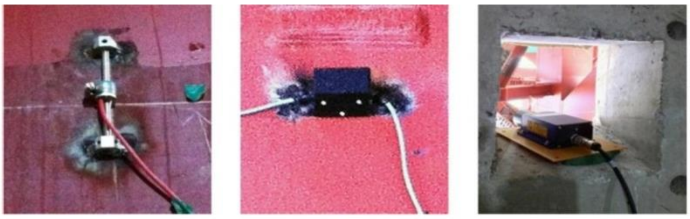


Figure 4: *Comparative vaccum monitoring sensor to detect the air leakage due to crack [4]*

Anand Kumar Jha [5] studied, Bridge Monitoring System for large span bridge monitoring. A 3-level distributed structure was adopted in the monitoring system, which includes central server, intelligent acquisition node and local controller. IEEE 802.11 wireless network was used to send processing results to local controller. 2G network was also used to transmit real-time data between central server and local controller. The results obtained by running intelligent monitoring system for large span bridge monitoring have shown that the proposed system was stable and effective. It is concluded that this system can help in monitoring the bridge in an efficient, cost effective and reliable manner and add up to a revolution in bridge safety monitoring, providing a heightened level of early-warning capability.

HyoSeon Park et al.[6] conducted the study of An Integrative Structural Health Monitoring System for the Local/Global Responses of a Large-Scale Irregular Building under Construction. In this study, a practical and integrative SHM system was developed and applied to a large-scale irregular building under construction. In the sensor network, customized energy-efficient wireless sensing units (sensor nodes, repeater nodes, and master nodes) were employed and comprehensive communications from the sensor node to the remote monitoring server were conducted through wireless communications. From the long term monitoring results recorded from a large number of sensors (75 vibrating wire strain gauges, 10 inclinometers, and three laser displacement sensors) indicated that the construction event exhibiting the largest influence on structural behaviour was the removal of bents that were temporarily installed to support the free end of the cantilevered members during their construction. Finally, the limitations were observed in the proposed wireless signal networking throughout the long-term monitoring, including the data loss caused by communication obstacles at the construction site. Therefore, the development of data recovery tools in terms of both hardware and software (e.g., such as signal processing methodology) is needed to enhance the reliability of monitoring results with data loss.



(a) (b) (c)

Figure 5: *Sensors **a)** VWSG; **b)** Inclinometer; **c)** Laser displacement sensor [6]*

Raffaella Di Sante reviewed Fibre Optic Sensors for Structural Health Monitoring of Aircraft Composite Structures: Recent Advances and Applications [7]. Recent advances and applications of Fibre Bragg Gratings (FBG) sensors, Brillouin and Rayleigh distributed sensors to the structural health monitoring of composite aircraft structures have been reviewed. To achieve the ultimate goal of establishing a standardisation framework for sensor quality, application and integration in the aircraft environment, as envisaged by Airbus in the forthcoming years, some additional research and development are required to ensure highly reliable detection capability, robustness in order to avoid signal loss in the case of fibre breakage, and maintainability to permit the replacement of damaged fibre sensors.

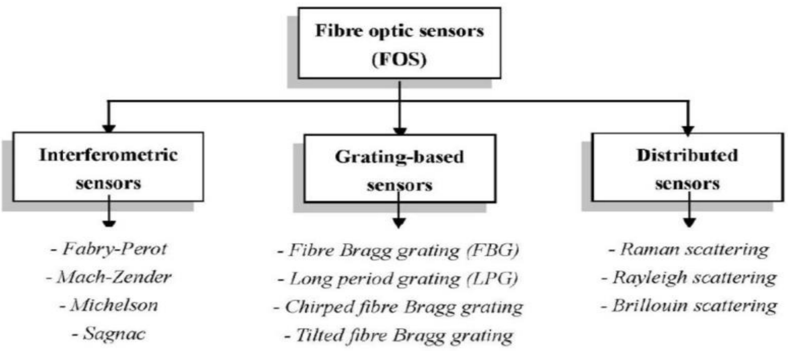


Figure 6: *Types of Fibre optic sensors [7]*

Hailing Fu et al.[8] highlighted a Structural Health Monitoring (SHM) system for Condition-Based Monitoring (CBM) application of Composite structures. This SHM system consists of a smart diagnostic film and a wireless passive impact detection system. The diagnostic film and the wireless impact detection unit are implemented and tested, showing the practicability of this combination in aircraft CBM applications. SHM unit provides a light-weight, compact, low-power impact detection system for on-board structural health monitoring.

A. P. Adewuyi et al.[9] investigated Vibration-Based Structural Health Monitoring Technique Using Statistical Features From Strain Measurements through experimental study. A statistical vibration-based damage identification algorithm to assess the stability of the measurement data, detect and locate damage in civil structures, where variability in response and modal parameters due to measurement noise and environmental influence is often inevitable. Through experimental investigation of a flexural structure using conventional strain gauges and long gauge Fibre Bragg Gratings (FBG) sensors, the importance of the technique for civil SHM is established and presented in an easy-to-interpret graphical format for effective implementation of results. This paper concludes that this method has capability to reliably assess the consistency of the measurement data, promptly identify faulty sensors and accurately locate damages in structure by using statistical features. This paper also concludes that the ability of strain gauges to correctly locate damage is limited to its short gage length, while the long-gage FBG sensors are more efficient choice for effective identification and localization of damage.

Sánchez J.C. et al.[10] has given the methods for Structural Health Monitoring Techniques for Damage Detection in Hydrogen Pressure Vessels. To identify the more adequate inspection methods to classify by smart rules based in artificial intelligence, the effect of an impact on the structural integrity of the pressure vessel, thus improving the level of safety. Structural Health Monitoring (SHM) provides a system with the ability to detect and interpret adverse changes in a structure like a pressure vessel. This paper states that the guided wave based diagnosis method is one of the most effective used techniques due to its sensitivity to small defects. This paper concludes that difficulty in analysis is the tank´s shape and the embedding of sensors. Creating a damage-sensitive structure that can be interrogated remotely may lead to a simple and easy solution.

I. Antoniadou et al.[11] reviewed the aspects of structural health and condition monitoring of offshore wind turbines. Advanced signal processing and machine learning methods are discussed for SHM and CM on wind turbine gearbox and blade damage detection examples. And initial exploration of supervisor control and data acquisition systems data of an offshore wind farm and data-driven approaches are given for detecting abnormal behaviour of wind turbines. Although difficulties exist related to the operational conditions of wind turbine systems. It also states that pattern recognition and machine learning approaches can not only be useful for the feature discrimination part of the SHM procedure, but also for the manipulation of SCADA data and it is shown on actual wind farm data that a population-based approach towards wind turbine SHM might be a successful choice.

Figure 7: *Wind turbine blade experiment under continuous fatigue loading [11]*

Charles R. Farrar et al. [12] studied structural health monitoring. Development of robust SHM technology has many elements that make it a potential 'grand challenge' for the engineering community. First, almost every industry wants to detect damage in its structural and mechanical infrastructure at the earliest possible time. Industries' desire to perform such monitoring is based on the tremendous economic and life-safety benefits that this technology has the potential to offer.

CONCLUSION

There are challenges with infrastructure that may limit the effectiveness of SHM system, which can offer the data transfer methods from various structures and long-term retention of that data. In order to make the SHM-based inspection cost-effective, it would be necessary to improve the sensor technology to reduce the weight of the sensor system and to detect damage in a long range.

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