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[1.] Dragoljub VUJIC

WIRELESS SENSOR NETWORKS IN AIRCRAFT DESIGN AND STRUCTURAL HEALTH MONITORING

[1.] Military Technical Institute, Belgrade, SERBIA

Abstract: *Aircraft industry faces many challenges to reduce both operational and maintenance cost. One of the possible ways for reducing these costs is the introduction of wireless sensor networks (WSNs). WSNs are already finding a variety of applications for both safety-critical and non-safety critical distributed systems. This paper deals with the application of WSNs for aircraft structural health monitoring. Special attention has been given to the WSNs design issues using available components on the market.*

Keywords: *Wireless sensor networks, aircraft structural health monitoring, micro-electro-mechanical systems, condition-based maintenance, sensor node*

INTRODUCTION

The weight of an aircraft directly impacts the operational cost. At present, a pound saving in aircraft weight translates to $100 savings per year per aircraft. Many innovations have in aircraft industry towards weight reduction. The percentage of composite, hybrid materials and advanced aluminum alloys in airframe have increased substantially over the years realizing significant weight benefits. However, full potential of composites, hybrids and advanced aluminum alloys, as substantial reduction in material allowable, are yet to be realized due to still prevailing conservative design philosophy. It is essential to increase the confidence in assessing fatigue, crack/delamination identification/growth and damage tolerance characteristics of these advanced materials. This will help in reducing conservatism built in current aircraft structural design leading to realization of slender aircraft airframe structures.

Over the last decade Wireless Sensor Networks (WSNs) have been successfully applied in many engineering fields such as: structural health monitoring (SHM), industrial applications, environmental monitoring, traffic controls, health applications, etc. This paper deals with application of WSNs for aircraft structural health monitoring.

STRUCTURAL HEALTH MONITORING

Generally speaking, the aim of structural health monitoring (SHM) is to monitor structures using embedded or attached non-destructive evaluation sensors and to utilize the data in order to assess the state of the structure. Often structures equipped with various types of sensors are compared to human nervous system as shown on the Figure 1. In the other words, Structural Health Monitoring is the imitation of the human nervous system. Having detecting the damage by the sensors embedded in the structure, the central processor, as a human brain, can build a diagnosis and decide what kind of actions have to be done.

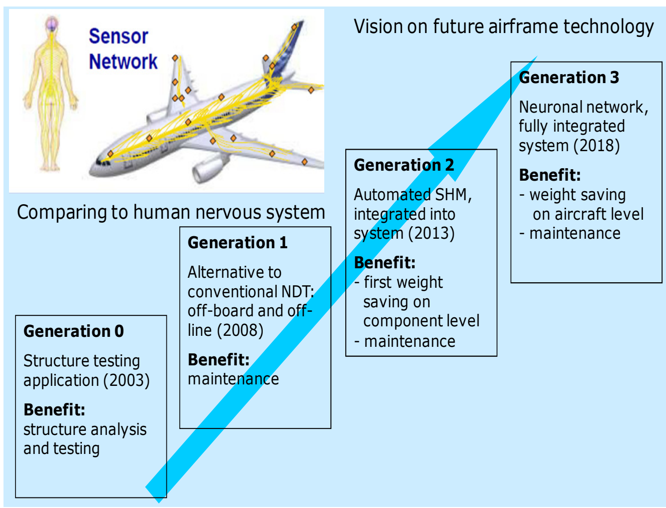

Figure 1. SHM application in Airbus

The Figure 1 presents a stepwise approach towards SHM application in Airbus. As we can see, the automated SHM will be integrated into system in 2013. The company expects to establish a fully integrated system in 2018.

SHM is a new and improved way to make a non-destructive evaluation with a minimum of manual intervention. It includes all monitoring aspects which are related to damages, loads and conditions, which have a direct influence on the structure. Knowing the integrity of in-service structures on a continuous real-time basis is a very important objective for manufacturers, end-users and maintenance teams. Structural health monitoring allows an optimal use of the structure, a minimized downtime, and the avoidance of catastrophic failures. Therefore, structural health monitoring drastically changes the work organization of maintenance services: by aiming to replace scheduled and periodic maintenance inspection with condition-based maintenance and by drastically minimizing the human involvement, and thus improving safety and reliability.

Traditionally, the sensors deployed on the structure are connected through coaxial wires. WSNs consistently reduce the installation and maintenance costs. Furthermore, the compact size and low cost of a single wireless sensor node enables the deployment of a large number of units on the monitored structure, especially in those locations difficult to be reached by wires, increasing the screening resolution of the system.

In the commercial and military aircraft there are a number of safety-critical and non-safety critical systems. These systems are based on wired connections and, therefore, they are complex and difficult to route. The Airbus A380, for instance, has over 300 miles of cables consisting of approximately 98.000 wires and 40.000 connectors. Replacement of the current wire harness-based sensors with a wireless sensor network (WSN) can help to achieve the goal of increasing the number of sensors, as well as, the system redundancy.

WIRELESS SENSOR NETWORKS TECHNOLOGY

Wireless network refers to any type of computer network which is not connected by cables. Wireless sensor networks (WSNs) consist of spatially distributed autonomous sensors designed to monitor physical parameters or environmental conditions, such as temperature, strain, pressure, vibration, sound, motion, pollutions, etc. Consequently, the sensors cooperatively pass their data through the network to a main location. The base station may communicate with the user or task manager node via Internet or Satellite. A wireless sensor, also known as a mote (reMOTE), smart dust, smart sensor or sensor node within the network performs the function of sensing, data processing and wireless data transmission. It is powered by an individual power source which often consists of a battery with a limited energy budget.

The development of WSNs largely depends on the availability of low-cost and low-power hardware and software platforms for sensor networks. With the micro-electro-mechanical system (MEMS) technology, the size and cost of a sensor node have been significantly reduced.

The nodes communicate wirelessly and often self-organize after being deployed in ad hoc fashion. Systems of 1000s or even 10.000 nodes are anticipated.

A sensor node typically consists of five main components (Figure 2). One or more sensors gather data from the environment and report the data to the microprocessor. A microprocessor is a central part of a wireless sensor node. It processes all the data that receives from memory, sensor, or transceiver. A transceiver communicates with the environment. It is used radio frequency (RF) as a transmission medium to send data wirelessly. The transceiver can take data from a microprocessor to send it over the air and vice versa. A memory is the main resource for storing programmes and intermediate data coming from the sensors or the transceiver. The size of the memory depends on the application of the sensor. The battery supplies all parts with energy. To assure a sufficiently long network lifetime, energy efficiency in all parts of the network is crucial. Although most sensors have a traditional battery, there is an early stage research regarding production of sensors without batteries, using similar technologies applied to passive radio frequency identification (RFID) chips without batteries. The sensor nodes are usually *scattered in a sensor field. Each of them has the capabilities to collect data and route data back to the base station.*

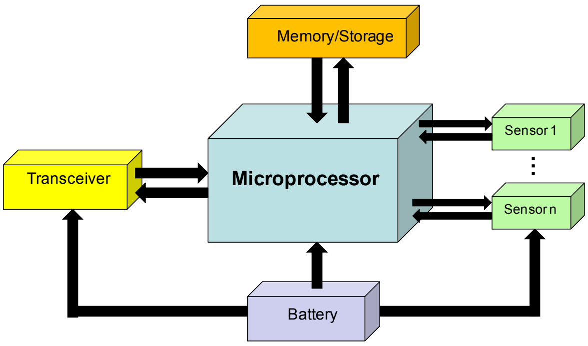

Figure 2. Hardware components of a sensor node

WIRELESS SENSOR NETWORKS DESIGN ISSUES USING AVAILABLE COMPONENTS ON THE MARKET

A well known USA company MicroStrain has deployed wireless sensors and wireless sensor gateways for a number of applications. Sensors that measure strain, acceleration, displacement, pressure, temperature, inertial loads, and torques have been combined in time synchronized networks to provide a rich amount of information for improved condition based maintenance. Sensors can be quickly deployed in discrete locations of the aircraft structure. With highly synchronized data sampling, and extended range communication, MicroStrains's WSN's are able to collect and aggregate data in a single database, and push it to the cloud for remote access.

The main features of the Lossless Extended Range Synchronized (LXRS) wireless sensor systems are as follows:

- *Losless wireless communications protocols provide 100 % packet success rate*
- *Extended Range radio link to 2 kilometers*
- *Scalable wireless sensor networks support continues, burst, and hybrid sampling modes*
- *Time Synchronized to +/-32 microseconds.*

The LXRS Wireless Sensing System works by leveraging advanced bi-directional radio communications protocols. When data are received without errors by the wireless sensor data aggregator (WSDA) base station, the WSDA sends an acknowledgement that these packets were received. Data that are not acknowledged remain within each LXRS sensor node's non-volatile memory for re-transmission according to the network scheduler. It has to be noted that data are time-stamped by each node at the time of analog-to-digital (A/D) conversion. Therefore, even when re-transmitted, all data are accurately time stamped.

Wireless accelerometer node

Wireless Accelerometer Node (The G-Link -LXRS) presented in Figure 3 features on-board triaxial ±2 g or ± 10 g MEMS (Micro-Electro-Mechanical Systems) accelerometers and an internal temperature sensor. G-Link -LXRS can be employed to measure vibration or acceleration, or as a tilt sensor or inclinometer. The G-Link -LXRS is compatible with any WSDA - Base, WSDA - 1000 or SensorCloud. At the heart of MicroStrain's LXRS Lossless Data Wireless Sensor Networks are WSDA (Wireless Sensor Data Aggregator) gateways, which use exclusive beaconing protocols to synchronize precision timekeepers within each sensor node in the network.

Figure 3. Wireless Accelerometer Node

The WSDA - 1000 Wireless Sensor Data Aggregator

The Wireless Sensor Data Aggregator (WSDA - 1000) presented in the Figure 4 is a single-board computer with Ethernet connectivity designed to operate as an integral part of MicroStrain LXRS Wireless Sensor Networks. The WSDA - 1000 is capable of collecting lossless data from a wide range of MicroStrain wireless sensor nodes operating in LDC or Synchronized sampling mode.

Figure 4. WSDA (Wireless Sensor Data Aggregator) – 1000

The general features and benefits of the WSDA - 1000 Wireless Sensor Data Aggregator are the following:

- *Programmable communication range from 70 m to 2.000 m*
- *Time Synchronized to +/-32 microseconds.*
- *2 GB non-volatile embedded flash for local storage*
- *Command, control, and monitoring of a remote wireless sensor network from user PC*
- *Full industrial temperature range supported (-40° C to 85° C)*

CONCLUSION

The aircraft industry will greatly benefit from the use of WSNs. These benefits through weight savings, reduction in subsystems design complexity and improved condition based maintenance will directly benefit the airlines in terms of additional revenues, as well as, lower operational and maintenance costs. Nevertheless, using wireless technology gives the potential to lead to more efficient future aircraft designs and quicker time-to-market.

Wireless Sensor Networks, based on some components available on the market, can be applied for aircraft structural health monitoring. The user has to choose the type of sensors which wants to apply. Sensors can be quickly deployed in discrete locations of the aircraft structure. As mentioned, the MicroStrains's sensing systems are ideal for both small scale applications requiring a few sensor nodes and large scale applications requiring hundreds of sensor nodes. Wireless sensor nodes are able to collect and aggregate data in a single database, and push it to the cloud for remote access.

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