Poster Abstract: Piezoelectric Energy Harvesting Powered WSN for Aircraft Structural Health Monitoring

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I. INTRODUCTION

Wireless sensor networks (WSN) have been widely used for a number of industrial monitoring applications including the aircraft industry. Indeed, the WSN paradigm ensures the fast deployment of sensing devices in difficult to access areas, the measurement of physical phenomena and transmission of data to a user over the wireless network. Due to autonomous nature of WSN, the energy resources of sensor nodes are limited by the energy stored in batteries.

The Energy Harvesting (EH) technology is promising in terms of guarantying the 'perpetual' operation of sensing devices by harvesting the ambient energy, e.g. solar radiation, vibrations, RF, and its storage in rechargeable batteries. However, batteries have a finite number of recharge cycles and, moreover, their application is prohibited in a number of industrial applications, including the aircraft industry, due to the potential risks associated with the batteries explosion.

In this work, we present the design and prototype of a self-powered sensor node for the aircraft structural health monitoring. The sensor node is powered by the ambient vibrations generated by the aircraft wings. Sensing devices perform the comprehensive condition monitoring of structures and systems, as well as measurement of environmental parameters, e.g. ambient temperature, ionizing radiation levels, to help operators in assessing the aircraft status at every stage of its mission. With the wireless communication the sensor nodes can be networked with no need for wiring which implies extra weight on board.

Until now few attempts have been made to address the problem of the aircraft structural health monitoring. These efforts were associated with wired or wireless monitoring systems which required continuous power supply for sensors and data transmission. The wired options implied the high cost of deployment, wiring complexity and extra weight. Moreover, wired monitoring systems assume the 'unlimited' availability of power needed to satisfy their performance requirements. This approach is unacceptable for WSN applications due to constrained power resources. A number of attempts have been made to develop WSN nodes powered by EH [1] in the context of aircraft structural monitoring. It requires a systematic engineering approach and multidisciplinary research.

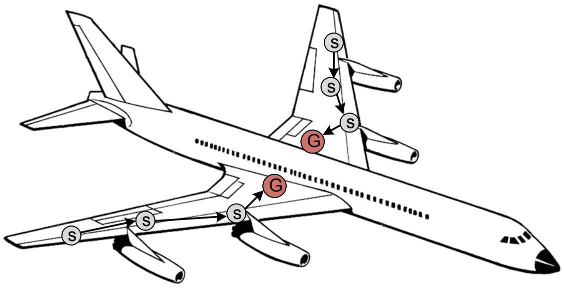

Figure 1. Aircraft structural monitoring using WSN: '*s*' – sensor nodes conduct measurements and transmit data to the gateway '*G*' over the wireless network.

An integrated system approach has been developed by the multi-disciplinary Energy Harvesting and System Research Group at the University of Exeter, previously at Cranfield University, to tackle this problem [1]. Some efforts have been made to investigate specific problems in the area, e.g. reduction of the node power consumption in active and sleep modes, as well as maximum power point tracking [2], and wireless data transmission in the aircraft environment [3].

The novelty of this work is in proposing the complete solution for the aircraft structural monitoring using self-powered wireless sensor nodes with the attention to power management problems and realistic scenarios.

Figure 1 presents a sketch of the WSN performing the aircraft structural monitoring. The sensor nodes '*s*' are placed inside the wing structure next to the engines for harvesting the vibrations of the aircraft structure, e.g. wings. The accurate location of the sensor nodes is defined basing upon the analysis of the wing characteristics, such as electric field and frequency of wing vibration. The sensor nodes perform the measurements of wing vibrations by accelerometers and transmit the data to the gateway '*G*' located at the wing root. The sensor nodes and the gateway are of the same hardware architecture. The WSN gateway collects all the packets and forwards them to the aircraft central processing system for further data processing. For example, it is of significant importance to track the wing vibrations and to detect unusual conditions, e.g. a bird impact on the wing structure during the aircraft mission.

II. SYSTEM OVERVIEW

The proposed hardware platform of wireless sensor node shown in Figure 2 includes five units: the energy harvesting,

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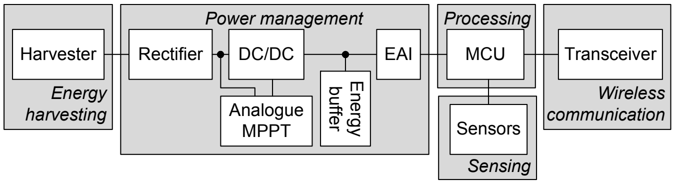

Figure 2. Block diagram of the wireless sensor node powered by vibrations.

power management, wireless communication, processing and sensing. All electronic components used in the design are to meet the following requirements: energy efficiency, small size, compatibility of the components and their simple interface.

The *energy harvesting* unit is realized by the EH component based on Macro-Fibre Composite (MFC) material. This EH component can be integrated with the wing structure and placed in a location where the highest strain energy is expected. The *power management* unit provides the pre-set voltage ranged between 2.5 V and 3.15 V for the sensor node. First, the unit *rectifies* the 'AC-based' ambient vibrations. The purpose of the *DC/DC* block is the energy transfer, rather than adjusting the duty-cycle for impedance matching. Capacitor, *energy buffer*, with the *DC/DC* block, operates as a buffer. The system energy is supplied by the capacitor if it is charged to the pre-set voltage. In order to achieve the highest efficiency of the power management unit we have implemented an *analogue Maximum Power Point Tracking (MPPT)* block which controls the operation of DC/DC with respect to its input power. *Energy Aware Interface* (EAI) monitors the voltage on the capacitor to let the system know when next transmission can be effectuated.

The *wireless communication* and *processing* units are implemented using the JN5168 wireless Microcontroller (MCU). The selection of wireless MCU was mainly driven by low power consumption, integration of transceiver and MCU in a single chip, functioning in industrial environment. The wireless transceiver supports IEEE 802.15.4 standard (ZigBee specification) and transmits in unlicensed 2.4 GHz ISM band. It has an integrated chip antenna used in this design. The *sensing* unit conducts the measurements of wing vibrations, temperature and humidity using the accelerometer, temperature and humidity sensors, respectively.

III. PRELIMINARY RESULTS

Figure 3 (a) shows the dynamic vibration test of the piezoelectric energy harvester integrated in carbon-fibre composite material that is currently used in the aerospace industry. The harvester is made of MFC M8528-P2 material and its size is 85x28x0.3 mm. The test is conducted using INSTRON tensile testing equipment under the following conditions. The strain level is 300 $\mu\varepsilon$, 400 $\mu\varepsilon$, 500 $\mu\varepsilon$, and 600 $\mu\varepsilon$. The frequencies are 2 Hz, 4 Hz, 6 Hz, 8 Hz, and 10 Hz. Figure 3 (b) shows the generated power. The harvested power is highly sensitive to the connected electric load due to changing impedance, Z, of the EH component. Also, the integration methods for the harvester and wing structure have a significant impact on the output power for the sensor node.

Indeed, getting the highest output power from the harvester is a task of top priority in terms of powering the sensor node.

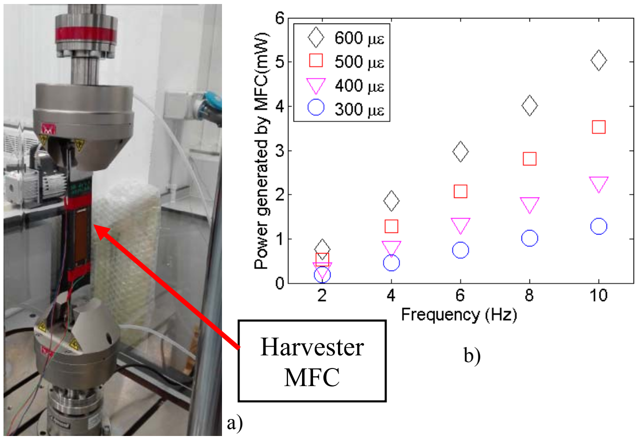

Figure 3. (a) Testing of fabricated harvester using INSTRON equipment, (b) power generated under various conditions.

TABLE I. SYSTEM EFFICIENCY, η_{TOT}, UNDER VARIOUS CONDITIONS.

C, mF	S, με	f, Hz	η_{TOT}
10	300	10	0.80
20	300	10	0.72
20	600	2	0.73
30	300	10	0.77

However, the overall efficiency, i.e. the ratio of harvested power and power delivered to the sensor node, is of vital importance in the scope of autonomous operation of the system. Table I lists the system 'best' efficiencies under various conditions where C is the capacity of the energy buffer, S is the strain, f is the frequency of structure vibrations, and η_{tot} is the total efficiency.

IV. CONCLUSION

We have presented an ongoing work and preliminary results in the scope of application of WSN to the aircraft structural monitoring. In particular, our main contribution so far is the design of architecture of the self-powered wireless sensor node, its prototyping and the investigation of its power management and power consumption.

Our future work aims at design and deployment of energy aware WSN for this application.

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