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ScienceDirect

Procedia Computer Science 37 (2014) 101 – 108

Procedia Computer Science

The 5th International Conference on Emerging Ubiquitous Systems and Pervasive Networks (EUSPN-2014)

Emerging Needs for Pervasive Passive Wireless Sensor Networks on Aerospace Vehicles

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Abstract

NASA is investigating passive wireless sensor technology to reduce instrumentation mass and volume in ground testing, air flight, and space exploration applications. Vehicle health monitoring systems (VHMS) are desired on all aerospace programs to ensure the safety of the crew and the vehicles. Pervasive passive wireless sensor networks facilitate VHMS on aerospace vehicles. Future wireless sensor networks on board aerospace vehicles will be heterogeneous and will require active and passive network systems. Since much has been published on active wireless sensor networks, this work will focus on the need for passive wireless sensor networks on aerospace vehicles. Several passive wireless technologies such as MEMS, SAW, backscatter, and chipless RFID techniques, have all shown potential to meet the pervasive sensing needs for aerospace VHMS applications. A SAW VHMS application will be presented. In addition, application areas including ground testing, hypersonic aircraft and spacecraft will be explored along with some of the harsh environments found in aerospace applications.

Peer-review under responsibility of the Program Chairs of EUSPN-2014 and ICTH 2014.

Keywords: Passive; Wireless; Sensor Network; Aerospace

1. Introduction

Wireless ubiquitous devices have been proposed to aid in many aircraft maintenance tasks such as reporting, documentation, asset tracking, and inspections [1-3]. However, NASA researchers desire pervasive Vehicle health monitoring systems (VHMS) sensor networks on board aerospace vehicles.

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Peer-review under responsibility of the Program Chairs of EUSPN-2014 and ICTH 2014.
doi:10.1016/j.procs.2014.08.018

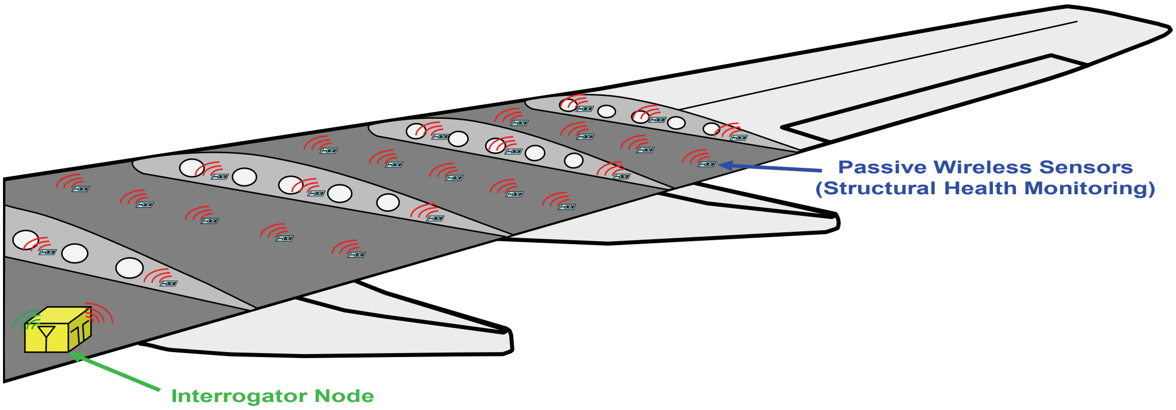

Fig. 1. Concept for pervasive passive wireless sensors for structural health monitoring for aerospace vehicles.

The proposed VHMS system would introduce passive wireless sensors attached to the structure for health monitoring. The interrogator node would interrogate the passive wireless sensors and would communicate wirelessly to conventional wireless sensor networks in a heterogeneous manner (Fig. 1). For complete VHMS coverage, many sensors would have to be attached to the vehicle's structure. However, constraints such as cost, mass, volume, and power often prevent the inclusion of wired VHMS instrumentation into aerospace systems. The elimination of wiring and wiring harnesses could reduce the total mass of the vehicle by 6~10% [4], and will reduce the impact of mass constraints from a VHMS system [5]. For example, the Space Shuttle had 300 miles of wiring which weighed over 17,000 pounds [6]. Much of this weight could be reduced by using passive wireless sensors. In addition to reducing weight, eliminating wiring and the supporting infrastructure will reduce fabrication costs [7]. Wires are prone to damage, such as nicks and breaks, and degradation due to wear, excessive heating, and arcing. Wiring problems can also stem from poor workmanship, such as improper crimps during initial fabrication or re-work. Wiring problems have led to major aircraft accidents and space vehicle launch delays [8]. When retrofitting a structure with VHMS sensors, using wireless instead of wired devices will avoid the need for expensive cable routing redesigns and the costs associated with performing safety re-certifications [9]. For these reasons, wireless microelectromechanical systems (MEMS) sensors are a priority technology that warrant NASA's attention during the next decade [10]. Unfortunately, existing wireless sensor systems have low data rates and require batteries; these two conditions make such systems undesirable. However, high data rate systems that do not require batteries, such as passive radio-frequency identification (RFID) sensors, are being developed.

The environments surrounding aerospace vehicles are typically harsh, with temperature extremes ranging from cryogenic to very high (>1000°C) for hypersonic (greater than Mach 5) vehicles experiencing aerodynamic heating due to skin friction. Hypersonic aircraft based on NASA's HyperX X-43 design will fly at Mach 10 and therefore require sensors that can withstand temperatures up to 1,282°C [11]. Many of these hypersonic vehicles contain cryogenic tanks requiring sensors that operate in very low temperatures >-150°C. Thus, hypersonic vehicles will need passive wireless sensors that can operate in harsh environments, such as those needed for other aeronautical applications.

Sensors are typically located in internal spaces allowing limited access, making the necessary periodic changing of batteries costly and time consuming. Furthermore, batteries perform poorly in extreme temperatures. In contrast to current wireless systems, passive wireless surface acoustic wave (SAW) sensors operate without batteries across a large temperature range. Passive wireless sensor networks are an emerging technology due to the numerous applications with limited use for battery-based systems. As a result, NASA is investigating the use of passive wireless sensors for aerospace applications because this technology could benefit many NASA missions. Small, passive, pervasive, wireless sensors that can operate in harsh environments will have applications in ground testing, conventional aircraft, hypersonic aerospace vehicles, rockets, and spacecraft.