Space Applications for Wireless Sensors

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ABSTRACT

From ground tests to operations on orbit and on the Moon, many space applications could benefit from small, passive, wireless sensors. Eliminating wires in spacecraft could reduce launch costs through the reduction of mass and lead to reduced fabrication costs. Development of wireless Vehicle Health Monitoring Systems (VHMS) will enable more sensors and increase safety. It is for these reasons that NASA is investigating the use of wireless technology for a variety of spacecraft applications. This paper will present a survey of opportunities for universities, industry, and other governmental agencies to partner in developing new wireless sensors to address the future sensing needs.

Keywords: wireless sensors, spacecraft, sensors networks.

1 INTRODUCTION

Reducing the weight of spacecraft will reduce both fabrication and launch costs [1]. The elimination of wiring and wiring harnesses could reduce the total mass of the vehicle by 6-10%, which lowers launch costs [2]. The cost of the mission can be reduced while increasing safety and reliability by incorporating more integrated Vehicle Health Monitoring systems (VHMS) [3]. Wireless sensor technology can reduce the weight and therefore the costs of spacecraft. The Decadal Survey of Civil Aeronautics identified that "self-powered, wireless MEMS sensors" warrant attention over the next decade [4]. Current wireless sensor systems have low data rates and require batteries. The environment of aerospace vehicles is often very harsh, with temperature extremes ranging from cryogenic to very high temperatures. For example, the Airforce's X-37B Orbital Test Vehicle could benefit from high temperature sensors mounted on the structure, as well as cryogenic sensors for monitoring fuel tanks. Passive wireless sensors are needed that operate across an extremely large temperature range where batteries do not provide adequate performance.

NASA recently instrumented an all Composite Crew Module for structural testing on the ground. Wireless sensors could reduce costs and the time to instrument a module before testing. NASA uses standard cables whenever possible, but custom cables are often required for unique test articles like the CCM. Custom cables are more expensive than standard cables. Additionally, it is time consuming to route, identify and validate cabling required for the hundreds of sensors on the CCM. If the cables are eliminated through the use of wireless sensors, then the time for cable setup would be eliminated and the overall costs would be reduced.

2 SPACE APPLICATIONS

The Space Shuttle would benefit from wireless sensors that can: track fatigue life, detect impacts, verify the environment, and maintain insight into the space shuttle as a system [5]. Passive RFID sensor tags are being investigated for monitoring over temperature conditions on the space shuttle thermal protection tiles [6]. Although the shuttle program is ending, the X-37B Orbital Test Vehicle was launched by the Airforce on April 22, 2010 (Fig. 1). Many space capsules and aerospace concepts still employ tile thermal protection systems, and will continue to do so in the future. These vehicles could benefit from passive wireless sensor systems.

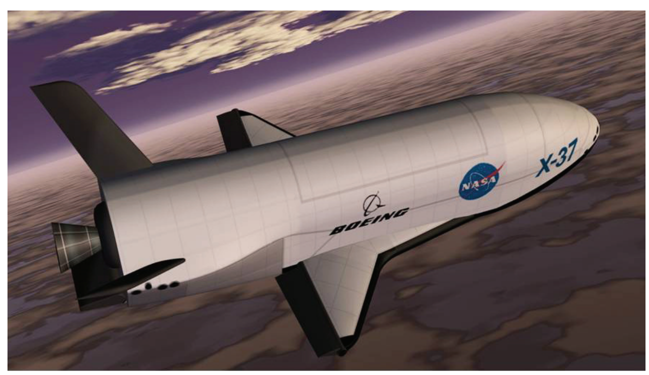

Fig. 1. Artist Conception of the NASA developed X-37 Orbital Test Vehicle.

The European Space Agency (ESA) [7], the Indian Space Agency [8], the National Natural Science Foundation of China [9], and NASA [10] are all investigating wireless sensor systems for operation on the lunar surface (Fig. 2). In addition, NASA is developing wireless sensor networks that can perform integrated system health monitoring of spacecraft and health monitoring of astronauts [11]. Italian [12], British [13], and American [14] researchers are also evaluating wireless sensor network operation for Mars exploration. The vision for extraplanetary exploration relies on wireless communications and wireless sensor networks. The systems being evaluated must connect

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landers, habitats, astronauts, robotic rovers, manned rovers, sensor probes, and sensorcraft together. Sensors and sensor nodes will play a large role in the data traffic on these networks. The environment of the moon is harsh with an operational temperature range of 100K to 400K at the equator, and a radiation dosage of 0.025 MRads (Si) protected with 2.54 mm of aluminum [15]. The lunar dust is charged positively during the day and charged negatively during the lunar night, causing dust plumes from the surface as the moon rotates [16]. Mars temperatures vary from 145K to 293K, with a radiation dosage of 0.01 MRads (Si) protected with 2.54 mm of aluminum. Sensors systems will have to be designed for operation in these extreme environments.

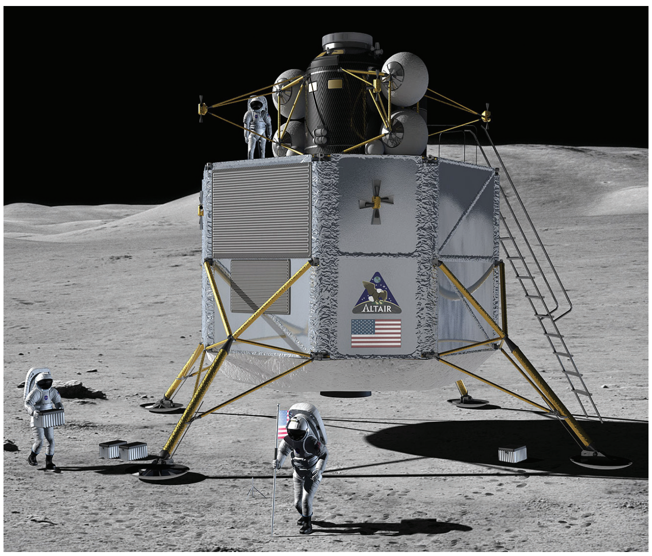

Fig. 2. NASA's Altair Moon Lander Concept

NASA's Constellation program developed a new series of rockets named ARES and a new crew exploration vehicle named ORION [17]. It has been identified that the ORION capsule needs wireless sensors [5]. The wireless system must be very low mass and be flexible and adjust to new needs and rapid implementation. The system must have high channel counts with distributed storage. The dynamic range must be large with high sample rates and must operate in harsh environments. The Orion capsule was designed to use standard aerospace materials, mainly aluminum. In 2006 the NASA Engineering and Safety Center (NESC) formed a multi-center team to investigate the design of an all Composite Crew Module (CCM) (Fig. 3). This module was developed in parallel to its aluminum counterpart to determine the feasibility of an all composite spacecraft. The goal was to determine crashworthiness, damage tolerance, and inspectability [18]. This design effort lead to a full scale composite capsule being fabricated and delivered to NASA Langley Research Center for testing in the Combined Loads Test System (COLTS) facility. Parts were tested for loads and impacts, and the entire structure was subjected to static testing at 31 psi (two atmospheres) internal pressure. For testing in COLTS, the CCM was instrumented with a variety of sensors: temperature, acoustic emission, conventional wire strain gauges, and fiber optic strain gauges. Many of the measurements were designed to give data that would be instrumental in the development of a VHMS system for the operational capsule.

Both the internal and external sensor cabling required for testing are visible in fig. 3. The CCM was covered in sensors; 280 strain gauges, 3000 Fiber Optic (FO) strain gauges, and 80 acoustic emission sensors. Before flight testing there is a need for wireless sensors that can reduce the amount of cabling, debug and setup time for ground testing applications.

Fig. 3. NASA's Composite Crew Module

NASA has also developed an alternative launch escape system to the rocket tower placed on top of manned rocket systems. The Max Launch Abort System (MLAS) is comprised of four solid rocket motors attached underneath the manned capsule and inside of a protective composite fairing (Fig. 4). The MLAS was launched successfully on July 8, 2009 from Wallops Island in Virginia. The main objective of the launch was to test for a stable trajectory during an unpowered portion of the flight. To monitor the capsule during flight, 176 sensors were flown. These sensors included 87 pressure sensors, 52 strain gauges, 23 accelerometers, 13 thermistors, and one microphone. A passive wireless implementation could have reduced the wiring weight required for this suite of sensors.

RFID tags were used as part of the Smart and Intelligent Sensor Project (SiSP) for the MLAS [19]. Although the tags were not flown, they were part of a payload demonstration project that included a suite of new smart sensor and wireless technologies that were evaluated for flight readiness. The use of the tags for ground support equipment and comparisons with the flight payload measurements will all aid in increasing the technology readiness level and likelihood of future flight opportunities for RFID sensors.

Fig. 4. NASA's Max Launch Abort System (MLAS).

The ARES 1-X rocket launched on Oct. 28, 2009 (Fig. 5), with over 906 sensors on board as part of the Development Flight Instrumentation (DFI) system [20]. The sensors measured the aerodynamic pressure and temperature at the nose of the rocket, and contributed to measurement of the vehicle acceleration and angle of attack. Of the 906 sensors listed as components of the DFI, 689 were simple sensors; 112 temperature sensors, 98 strain gauges, 108 accelerometers, and 371 pressure sensors. Wireless sensors could eliminate much if not all of the cabling weight for these measurements.

Fig. 5. ARES I-X rocket at NASA's Kennedy Space Center

Several companies have begun development of commercial rockets. SpaceX and Orbital Sciences Corporation have both won NASA contracts for development of rockets that can carry supplies to the International Space Station (ISS). These new rockets will have the same requirements for low mass, low power, passive wireless sensing.

3 WIRELESS SENSING ISSUES FOR SPACE APPLICATIONS

Temperature extremes, ionizing radiation, vibration, are just a few of the issues that arise from the space flight environment. Component failures from the high levels of shock and vibration are not uncommon. Some systems see pressure variations from vacuum to high pressures. Corona discharge and arcing at low pressures sometimes pose a problem. This issue depends on the voltages of the components, the distance between the voltages and grounds, and the pressure. Ionizing radiation is a constant issue in space. The problem is exacerbated by shrinking feature sizes in each new generation of electronics. Volume, mass, and power, which are major concerns for all spacecraft systems, will have to be addressed.

Sensor networking protocols must be robust and fault tolerant while at the same time power efficient with little overhead. Synchronization is a major concern for some sensor nodes. Receiver systems must be able to handle aggregated data from large numbers of nodes both efficiently and with little power [21].

RF communication issues pose a significant challenge to implementing wireless systems successfully. Modulation methods must be chosen to allow large numbers of devices to communicate without interference within enclosed metallic structures, such as the interior of spacecraft. The RF communications must be secure and not open for hacking or jamming. Encryption and spread spectrum communications may be necessary. The bandwidth must be utilized carefully to enable high data rates, while adhering to regulatory limitations. Encoding schemes must be developed to allow for efficient operation in noisy environments. Also, the frequency of operation must follow international spectrum regulations. Another concern is electromagnetic interference, which poses a problem for every wireless system. Furthermore, all flight wireless electronics must be designed to pass tests for both electromagnetic compatibility and interference.

Certification of wireless sensor networks for flight is another issue that must be addressed. This includes the allocation of frequencies for wireless sensing on spacecraft, along with the determination of RF power levels, and FCC acceptance for spacecraft use. There is a concern that wireless devices within the cabin may interfere with spacecraft antennas located outside the cabin. This is similar to the problem on aircraft when passengers must turn off all wireless devices on takeoff and landing.

4 CONCLUSION

Passive wireless sensor technology offers many opportunities for application to VHMS sensing. NASA applications include acceleration, temperature, pressure, strain, shape, chemical, acoustic emission, and ultrasonics. Each of these applications has its own requirements and issues. Wireless sensing technologies offer many benefits that will allow the incorporation of large numbers of passive wireless sensors onto spacecraft. Since no single technology can answer all problems, research into all forms of wireless sensor must be performed in order to find the optimal solution for each aerospace application. Opportunities exist for universities and industry to partner with NASA in the development of new wireless sensors to address the future sensing needs of space vehicles.

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