Implementation of Wireless and Intelligent Sensor Technologies in the Propulsion Test Environment

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Introduction

From the first Saturn V rocket booster (S-II-T) testing in 1966 and the routine Space Shuttle Main Engine (SSME) testing beginning in 1975, to more recent test programs such as the X-33 Aerospike Engine (Fig1), the Integrated Powerhead Development (IPD) program (Fig 2), and the Hybrid Sounding Rocket (HYSR), Stennis Space Center (SSC) continues to be a premier location for conducting large-scale propulsion testing[1]. Central to each test program is the capability for sensor systems to deliver reliable measurements and high quality data, while also providing a means to monitor the test stand area to the highest degree of safety and sustainability. As part of an on-going effort to enhance the testing capabilities of Stennis Space Center, the Test Technology and Development group is developing and applying a number of wireless and intelligent sensor technologies in ways that are new to the test existing test environment.

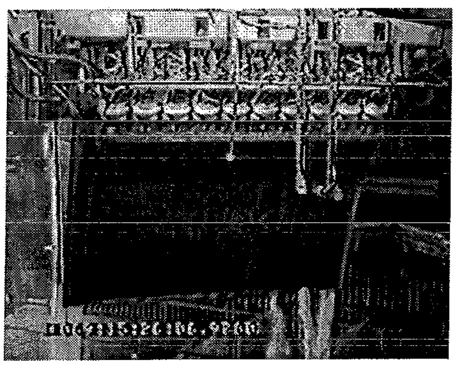

Figure 1: Linear Aerospike Engine

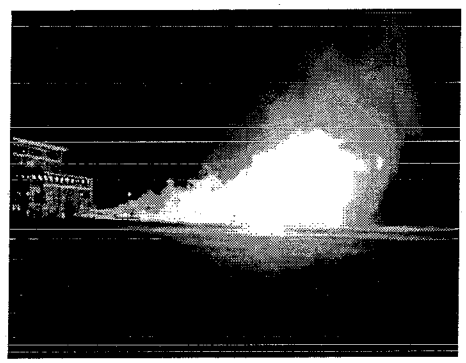

Figure 2: Integrated Powerhead Development (IPD)

Preliminaries

Wireless and intelligent sensor technologies being implemented in the propulsion test environment have come from both in-house development efforts as well as external sources. One of the in-house efforts has focused on the development of a Wireless Sensor Suite. In addition to serving as a demonstration system to help determine how, where and when wireless sensors can best be applied at SSC to facilitate large-scale engine testing, the sensor suite serves two primary purposes. First, the suite provides an easily configurable and deployable data collection capability for a variety of sensor types, wirelessly or using Ethernet. Second, it serves as an upgradeable platform that evolves to accommodate new technologies and smart sensor paradigms, both in the laboratory and industrial environment. Of particular interest is the continued tracking of the availability of network ready plug-and-play sensors aligned with the IEEE 1451.4 standard for smart transducers and networks[2] and the application of low cost, wireless solutions to the distributed sensor networks that can play a key role in intelligent condition-based maintenance and health monitoring systems[3]. The P1451.4 is a standard defining an interface specification for analog transducers based upon the use of a Transducer Electronic Data Sheet (TEDS). The TEDS contains manufacture information, calibration data and transducer characteristics and parameters that are transmitted from the sensor on power-up before entering analog mode for normal operation[4] (Fig 3).

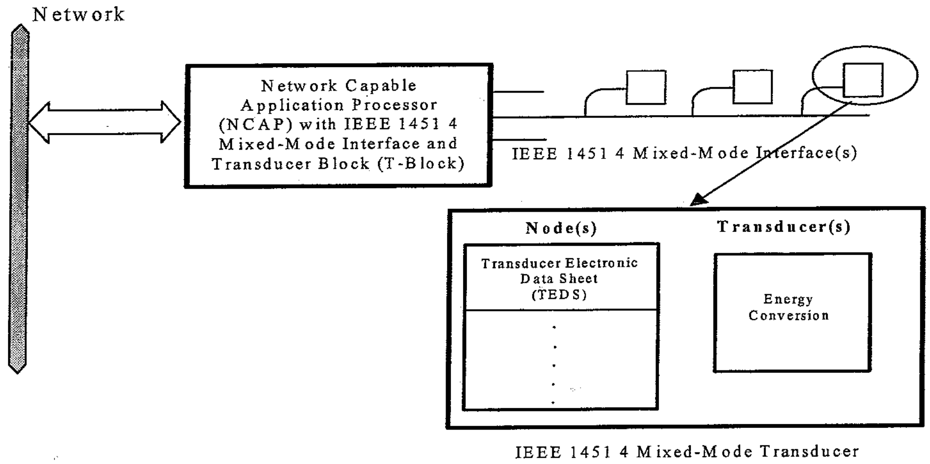

Figure 3: Context for the Mixed-Mode Transducer and Interface

The Wireless Sensor Suite arose, in part, from data needed by researchers interested in the acoustic, strain and vibration levels introduced to test facility structures generated by the testing of a 650K Ultra Low Cost Engine thrust chamber[5] (Fig 4,5,6). This required the use of six microphones, thirteen accelerometers, and nine strain gages positioned both external to and inside the E complex building high bay area and the E1 control room.

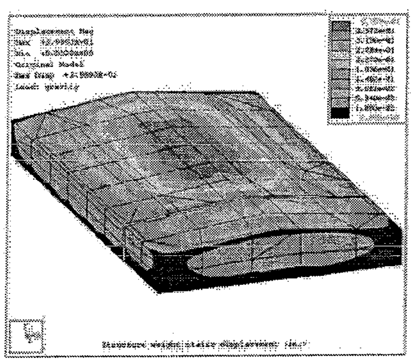

Figure 4: Prediction of sound level impact on building structures.

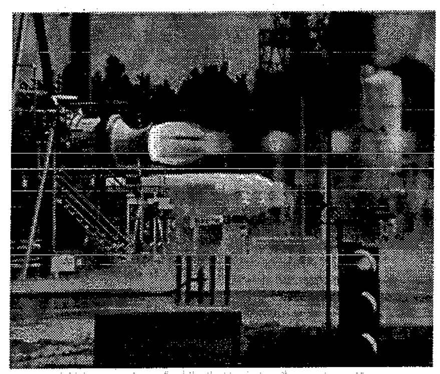

Figure 5: 650K Ultra Low Cost Engine thrust chamber testing

Figure 6: E1 test stand during 650K Ultra Low Cost Engine thrust chamber testing

A low-cost MEMS-based accelerometer system (MEMBAS) that included the use of an integrated circuit containing both the accelerometer transducer element and the necessary signal conditioning electronics[6] was designed to address this immediate need. Expansion on this concept to add wireless capabilities and the adaptability to accommodate multiple sensor types, led in turn to the development of the Wireless Sensor Suite[5] (Fig 7). Using a frequency hopping spread spectrum (FHSS) radio modem, microcontroller and associated electronics, the suite is designed with a modular architecture to allow configuration for a variety of sensor types, processing capabilities and communication mediums, whether over-air or cable. This architecture is designed with the intention to evolve to accommodate new technologies and smart sensor paradigms, both in the laboratory and industrial environment.

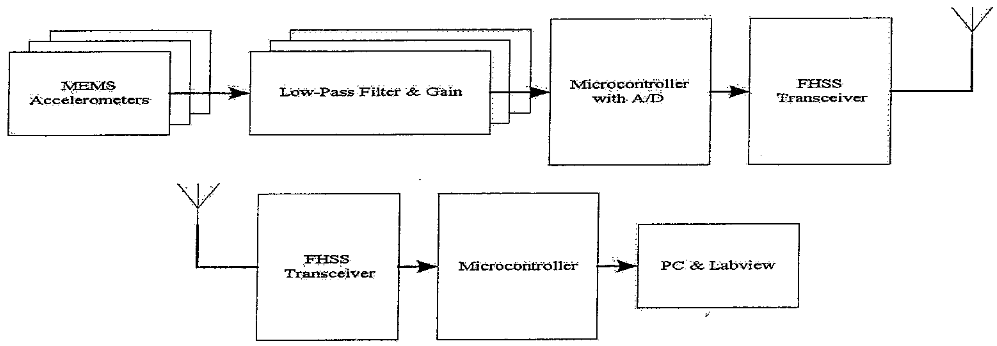

Figure 7: Wireless Sensor Suite MEMS accelerometer application

Another application of this sensor suite concept is the monitoring of vacuum levels on the vacuum-jacketed propellant lines. An Internet-enabled wireless vacuum monitoring network is slated for use on the network of cryogenic propellant lines on the A1, A2 and propellant barges to wirelessly read and report the vacuum level of the cryogenic lines to an on-site webpage (Fig 8).

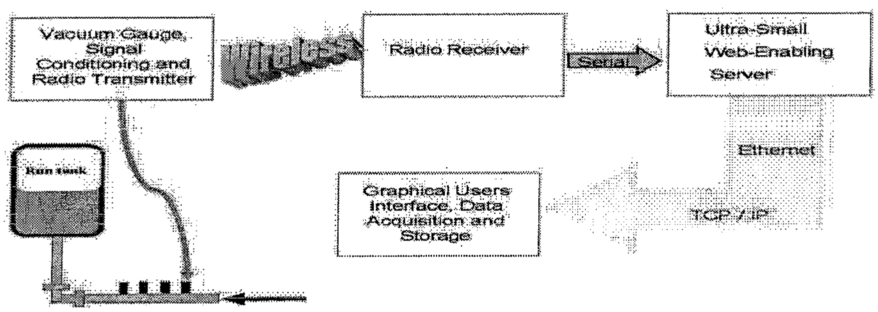

Figure 8: Internet-enabled Wireless Vacuum Monitoring Network

Results

On example of the full implementation of a production version of the Sensor Suite and associated graphical user interface to a specific propulsion test safety application, is in the use of the wireless sensors to monitor the safety of barrels storing high-concentration hydrogen peroxide propellant for the testing of a low-cost upper-stage propulsion system testing. Hydrogen peroxide use as a propellant is attractive due to the ease at which it can be stored for long periods of time without the need for cryogenic temperatures. It is critical however, that the temperature of storage containers be continuously monitored to ensure unstable conditions do not develop due to contamination. One indication of contamination will be a steady rise of surface temperature as the hydrogen peroxide decomposes. The Wireless Temperature Sensor Network (WTSN) was adapted to continuously monitor barrel temperature (Fig 9) and report directly to the control room (Fig 10) via a Labview graphical users interface (GUI)[7]. The system automatically alarms if any temperatures reported from the network exceed the preset alarm threshold. Data is logged and displayed on a local PC as well as to an on-site webpage.

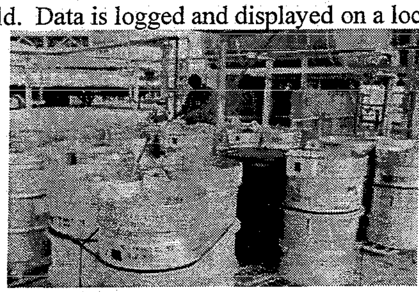

Figure 9: WTSN monitoring of H202 storage barrels.

Figure 10: E3 complex control room WTSN monitoring.

The Wireless Temperature Sensor Network is composed of multiple Transmitter Units (Fig 11) and a single Controller Unit (Fig 12) that provides a thermocouple interface and wireless connectivity to achieve an end-to-end accuracy of +/- 1 °C over an operating range of 0 °C to 200 °C. Four type-K thermocouples and one ambient solid-state temperature sensor provide temperature measurements for each field unit. The Controller Unit reports ambient and thermocouple temperatures to a PC via the 19.2 Kbps RS-232 serial port. A parallel printer port can print hardcopies when using the Controller Unit without a PC. Two normally-open dry contacts on the Controller Unit are closed when any reported temperature exceeds 40 °C. The dry contacts are intended for activating a local alarm. Since the barrels are stored out of direct sunlight, it is expected that surface temperatures above 40 °C will be indicative of internal, not external, barrel heating. Wireless connectivity is provided using 100-milliwatt frequency-hopping spread spectrum modules operating within the 900 MHz ISM Band under Part 15 of the FCC Rules. Transmitter Units operate on AA batteries for approximately 120 days with a 30-minute reporting duty cycle. A graphical user interface is provided to monitor and record the data to a PC and to provide a strip chart display of each sensor. The user also has the option to view the data over the Internet from the Test Technology website.

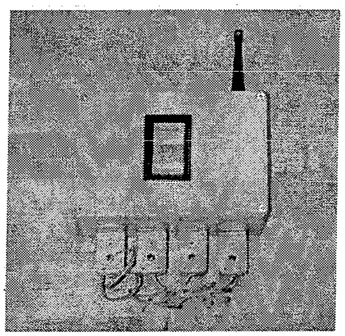

Figure 11: Transmitter Unit

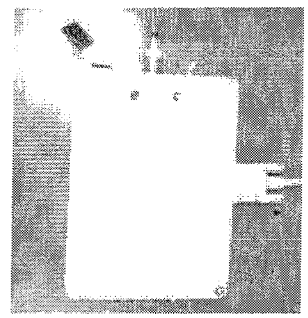

Figure 12: Controller Unit

Conclusion

Wireless and intelligent sensors are being developed and applied to a variety of engine test applications at SSC. A Wireless Sensor Suite has been developed to provide for an easily configurable and deployable data collection capability as well as serve as an upgradeable laboratory and field platform that evolves to accommodate new technologies and smart sensor paradigms. One promising application is to use this system as a platform for experimental demonstration of facility health monitoring using arrays of intelligent networked sensors.

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