Improved Testing Capability and Adaptability Through the Use of Wireless Sensors

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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 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. Sensor wiring is routed along piping and through cable trenches, making its way from the engine test area, through the test stand area and to the signal conditioning building before final transfer to the test control center. When sensor requirements lie outside the reach of the routine sensor cable routing, the use of wireless sensor networks becomes particularly attractive due to their versatility and ease of installation. As part of an on-going effort to enhance the testing capabilities of Stennis Space Center, the Test Technology and Development group has found numerous applications for its sensor-adaptable wireless sensor suite. While not intended for critical engine measurements or control loops, in-house hardware and software development of the sensor suite can provide improved testing capability for a range of applications including the safety monitoring of propellant storage barrels and as an experimental test-bed for embedded health monitoring paradigms.

Figure 1: Linear Aerospike Engine

Figure 2: Integrated Powerhead Development (IPD)

Wireless Sensor Suite Applications

The electronics industry has seen an explosion in the availability of powerful microprocessors for embedded systems, ultra-small web-enabling server systems and spread spectrum radios. The Wireless Sensor Suite provides a platform for experimentation and familiarization with these technologies and the range of operational features offered by the variety of suppliers. 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).

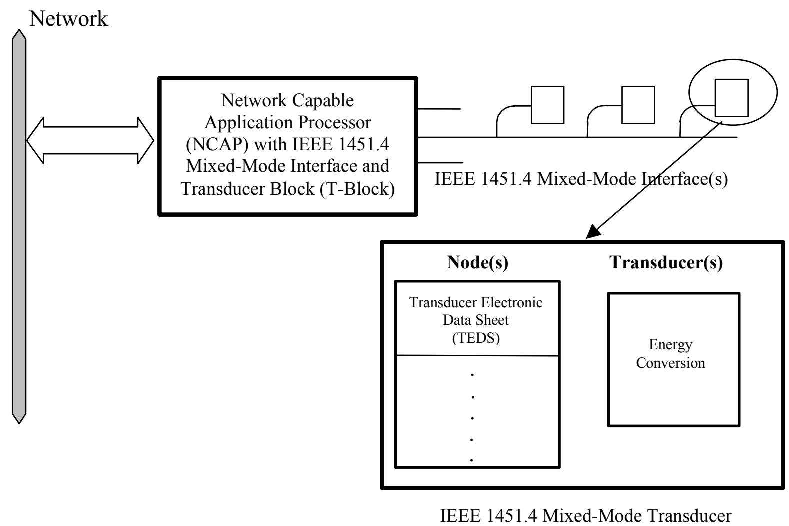

Figure 3: Context for the Mixed-Mode Transducer and Interface

Several instances of the Wireless Sensor Suite application efforts underway at Stennis Space Center will be briefly described here. For example, measurements were taken of 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. One of the largest field issues was cable protection and routing. Unlike sensor cables directly associated with the engine that generally stay in place during and between test sequences, these cables either had to be completely removed after each test (microphones) or at the end of the test sequence (accelerometers and strain gages). Additionally, the bulky signal conditioners associated with the sensors and power supply cables were moved into and out of the area prior to and after each test.

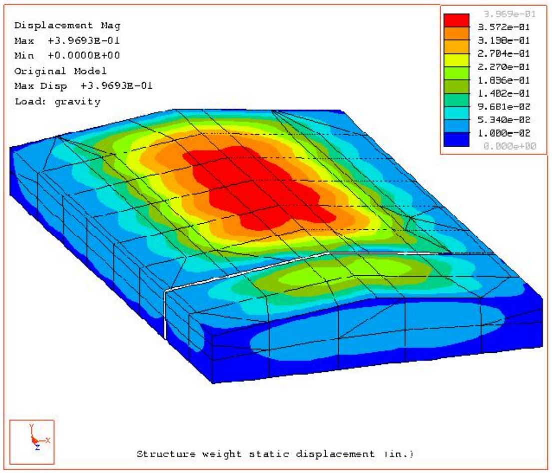

Figure 4: Prediction of sound level impact on building structures.

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 was developed to provide improved testing capabilities. It also serves 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.

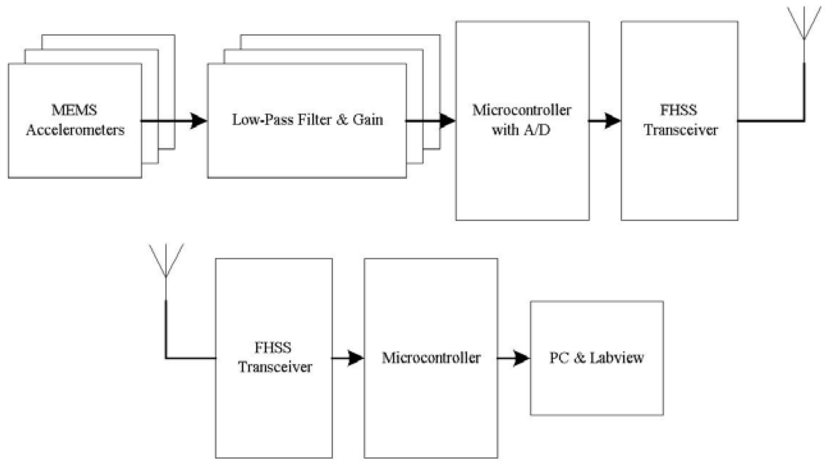

Figure 7: Wireless Sensor Suite MEMS accelerometer application

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 (IWVMN) has been designed 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).

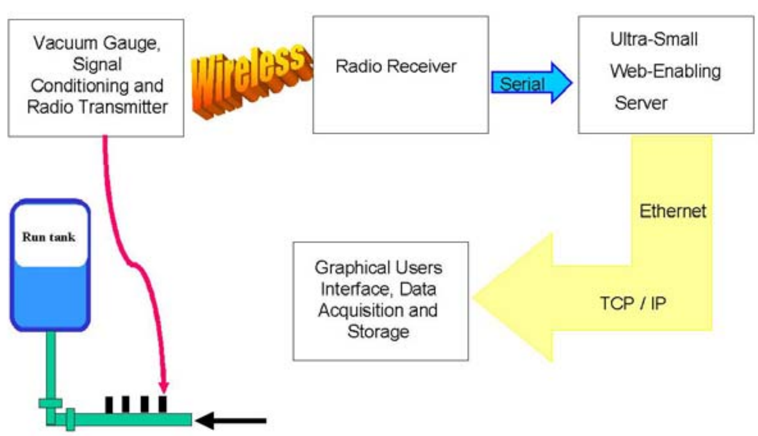

Figure 8: Internet-enabled Wireless Vacuum Monitoring Network

Additional sensor requirements also arise due to unanticipated measurement issues. For example, wireless sensors have been applied 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. Forty barrels have been continuously monitored in the E3 complex since January, 2003.

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 30 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 (Fig 13). The user also has the option to view the data from the Test Technology website. The only maintenance required is replacement of the Transmitter Unit batteries and desiccant.

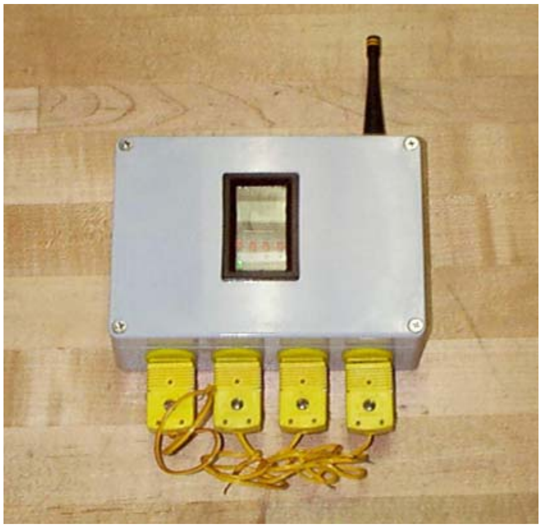

Figure 11: Transmitter Unit

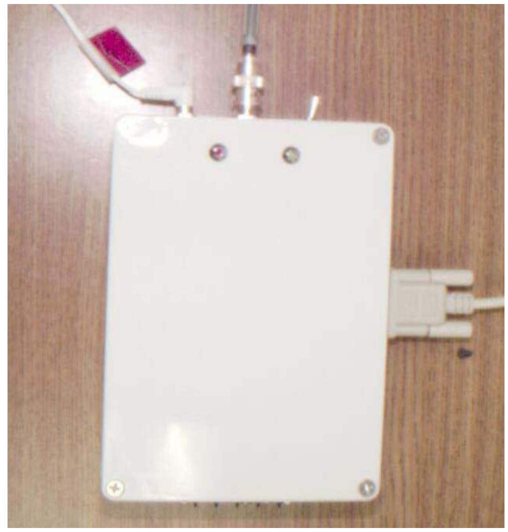

Figure 12: Controller Unit

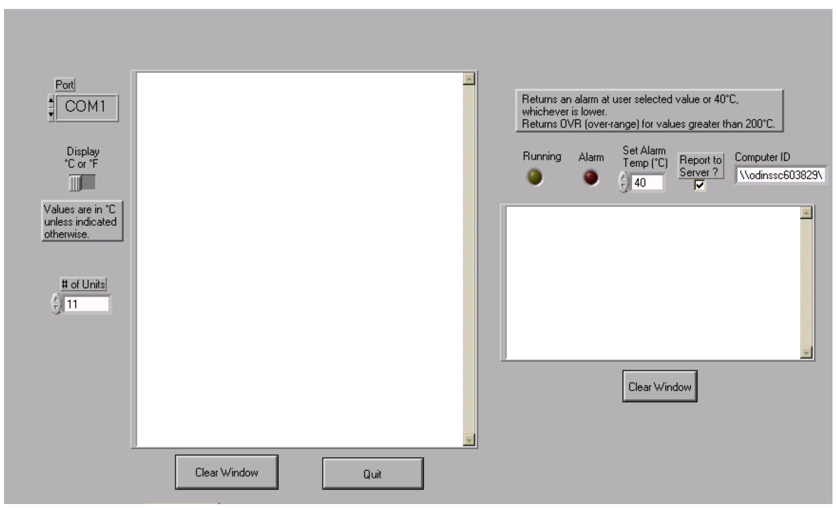

Figure 13: WTSN Graphical Users Interface

Conclusion

Wireless sensors are being applied to a variety of engine test applications at SSC. A Wireless Sensor Suite has been developed, which consists of remote sensor configurations using spread spectrum radios to communicate with a host data acquisition system. Example applications discussed include wireless accelerometers, vacuum gauges and thermocouples. The Wireless Sensor Suite also serves as a platform for evaluating embedded systems, small web-enabled servers, and spread spectrum radios that are readily available off-the-shelf. Other opportunities and issues for this wireless capability are currently being pursued. One promising application is to use this system as a platform for experimental demonstration of facility health monitoring using arrays of networked sensors.

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